Intravenous Stand Design

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ABSTRACT

This project investigates the types of intravenous stands currently used in Chinese hospitals. Through interviews with patients and nurses, we identified the strengths and weaknesses of existing designs. Based on the desires of the hospitals, an original IV stand design was created which will accommodate patients while in and while out of bed. Once the design was completed, a prototype was manufactured and rated with respect to existing designs. A low fluid alarm was also designed and manufactured.

TABLE OF CONTENTS

ABSTRACT 2
TABLE OF CONTENTS 3
TABLE OF FIGURES 5
1 INTRODUCTION 6
2 BACKGROUND 7
2.1 IV Stands in America 7
2.2 IV Stands in China 8
2.2.1 Internet research 8
2.2.2 Hospital Visit 9
2.3 Low Fluid Alarm 10
2.4 Objectives 11
3 Methodology 12
3.1 Design Validation 12
3.2 Part Design/Selection 13
3.2.1 Base 14
3.2.2 Lower Pole 15
3.2.3 Connection 15
3.2.4 Height Adjustment 16
3.2.5 Upper Pole 17
3.3 Low Fluid Alarm 17
4 Results 19
4.1 Product Analysis 19
4.1.1 Stability (30%) 19
4.1.2 Maneuverability (20%) 20
4.1.3 Ergonomics (20%) 21
4.1.4 Easiness of Realization (10%) 21
4.1.5 Easiness of Dismantling (10%) 22
4.1.6 Cost (10%) 22
4.1.7 Decision Matrix 23
4.2 Original Design 24
4.2.1 Base 24
4.2.2 Lower Pole 24
4.2.3 Connection 25
4.2.4 Height Adjustment 26
4.2.5 Upper Pole 31
4.3 Prototype 31
4.4 Design Validation 32
4.5 Alarm 33
4.5.1 Alarm 1 34
4.5.2 Alarm 2 35
5 Conclusion 36
6 Bibliography 38
7 Appendices 39

TABLE OF FIGURES

Figure 1: Simple Free Standing Designs 7
Figure 2: Dyaun IV Pole 8
Figure 3: Hanging IV Stand 8
Figure 4: Current IV Stand 9
Figure 5: Hospital Room 10
Figure 6: Low Fluid Alarm 10
Figure 7: Preliminary Design 13
Figure 8: Base Designs 14
Figure 9: Stability Analysis 20
Figure 10: Decision Matrix 23
Figure 11: Connection - Upper Tube 25
Figure 12: Connection - Lower Tube 25
Figure 13: Connection - Connected 26
Figure 14: Preliminary Height Adjustment 26
Figure 15: Height Adjustment Force Analysis 27
Figure 16: Required Spring Force for Height Adjustment 27
Figure 17: Required Spring Force 28
Figure 18: Height Adjustment Spring Selection 29
Figure 19: Height Adjustment Model 30
Figure 20: Completed Prototype 31
Figure 21: Updated Decision Matrix 32
Figure 22: Alarm Circuit 1 34
Figure 23: Alarm Circuit 2 35
Figure 24: Bent lower pole 36
Figure 25: Connection 49
Figure 26: Lower Pole and Base 49
Figure 27: Upper Pole and Height Adjustment 50
Figure 28: Complete assembly 50

1 INTRODUCTION

The purpose of this project is to design an improved system of supporting intravenous solution containers. Despite the prominence of intravenous usage worldwide, the IV stand has commanded very little interest for improvement over the past several decades.

In general, the solution container must be held approximately one meter above the point of injection. Beyond this function, any other feature of an IV stand simply contributes to comfort and convenience for the patient and hospital. In order to improve upon current IV stand designs, the benefits and drawbacks of currently used stands must be determined.

IV stands currently in use in Chinese hospitals accomplish this goal by hanging from the ceiling above the patients' beds. Although this design works quite well while the patient is in bed, it does not allow the patient to leave the confined area of the hanging IV stand easily or comfortably. We intend to create a new IV stand design to accommodate patients while in and while out of bed.

In addition to improving upon the IV stand, we also intend to design and manufacture an alarm which will alert patients and nurses when the IV fluid reaches a critically low level and must be refilled.

2 BACKGROUND

There is a large variety of intravenous stand designs currently in use. A single hospital must employ several different methods of supporting the intravenous solution container during a single patient's hospital visit.

2.1 IV Stands in America

The most common type of IV stand found in American hospitals is the free-standing mobile pole. All designs of this type are very similar. The primary difference is found in the design of the base, although the hangers and accessories may also vary slightly.

Figure 1: Simple Free Standing Designs

The IV poles shown in Figure 1 are manufactured by Invacare. They each have two circular hangers, which ensure the IV container will not fall off. They are also height adjustable from 43”-81” by loosening the adjustment screw and sliding the upper tube up or down. Stands of this design are usually on casters which make them very easy to move, by either the patient or a nurse. This gives the patient the opportunity to get out of bed and comfortably move around on his own.

The primary disadvantage of this design is that it is prone to falling over. The large height and relatively small base make it somewhat unstable. This type of IV stand also takes up floor space in the hospital room, and can be a hazard to the patient or visitors, although most American hospital rooms are large enough to accommodate the stand.

Figure 2: Dyaun IV Pole

A more advanced free-standing IV pole, shown in Figure 2, was recently designed and introduced by two graduate students in America. Although this stand is not in use at this time, it does offer a glimpse of a "better" IV stand design. The attributes of previous designs that were viewed as shortcomings by these graduate students should also be considered in our design.

This design offers a simplified height adjustment, a way to organize tubes and wires, wheel brakes, a handle, and an overall more pleasing appearance and feel. However, some drawbacks of the simple IV pole also apply to this design; primarily the possibility of falling over. Cost also becomes an issue with a new and complex design such as this.

2.2 *IV Stands in China*

Figure 3: Hanging IV Stand

Since our IV stand will be designed for Chinese hospitals, a more thorough study of IV stands used in China is necessary.

2.2.1 Internet research

The research began the same, with internet searches for current IV stand designs. Many free-standing poles, very similar to American designs, were found. However, a second type of IV stand was also found. It consists of a track in the ceiling above each bed with a pole hanging from a slider. The pole has a set of hooks at an adjustable height, as shown in Figure 3. This type of IV stand limits mobility to the range of the track, but increases stability.

2.2.2 Hospital Visit

In order to determine which type of IV stand is most frequently used in Chinese hospitals and the opinion of patients and nurses concerning the current stand, the team arranged trips to Tongji Hospital and a small hospital on HUST campus. The size and budget of the hospital had a significant impact on the results of our investigation.

Figure 4: Current IV Stand

In the small hospital we found hanging stands above each bed in the patient rooms as shown in Figure 4. There was no mobile stand available, so when patients needed to move around they were forced to carry the intravenous solution over their head. In the sitting area there was a free-standing IV stand to use, but the base did not have wheels and there was no height adjustment.

We spoke with a patient using the IV stand in the sitting room. He explained that patients were satisfied with the current system. Patients at this hospital do not have enough money to spend on convenience items, such as a mobile stand. They are simply interested in getting quality treatment at the least expensive price.

Tongji Hospital also uses the hanging IV stand above each bed. Therefore, a second IV stand must be retrieved from storage when the patient and bed are to be moved. This stand, simply a pole with a set of hooks on top, is inserted into a hole in the bed. If the patient is well enough to walk while on intravenous, the IV solution container again must be carried high above the head by the patient or nurse.

Despite the similar IV stands at the two hospitals, the reaction we got from patients and nurses was quite different. The factor we found to be of least concern to Tongji, a large hospital, is cost. The primary concern is always safety in a hospital setting. The next level of importance includes factors contributing to comfort and convenience: mobility, height adjustment, and appearance. Mobility is of particular importance. Simply using the bathroom is quite difficult with the current situation. Patients showed interest in having the ability to get out of bed and walk around.

Figure 5: Hospital Room

An additional observation in the hospital was how crowded the patient rooms are. There can be up to six patients in each room. Figure 5 shows how close together the beds are. This feature of the hospital is important to the design of the IV stand since there is little extra space to keep and maneuver several mobile stands in these rooms.

2.3 Low Fluid Alarm

During our hospital visits, the patients and nurses also expressed a desire for an alarm which would alert them when the IV solution level in the container became critically low. If nurses are busy with other tasks, a patient might not notice that their IV solution was about to run out. An alarm would ensure that the nurses are aware of this situation.

Figure 6: Low Fluid Alarm

Again, it was possible to find existing products of this type through internet research. The device shown in Figure 6 attaches to the intravenous tube and detects when there is no more fluid in the tube. It then emits a aural alert.

This is a simple and effective design, but it is also quite expensive, at 272 yuan each. It is felt that a similar device could be constructed for a much lower cost.

2.4 Objectives

After completing the background research we were able to specifically define the objectives of the project. We determined that there are many IV stands currently available, so we first need to evaluate the existing IV stands. If it is decided that none of the existing designs adequately satisfies the design requirements, an original design must be created, manufactured, and evaluated.

3 Methodology

After completing the background research the first task was to analyze all of the collected data. It was necessary to determine the shortcomings of current designs in order to validate the need for a new design.

3.1 Design Validation

The primary shortcoming of the IV stands currently in use at these hospitals is their lack of mobility. The hanging IV stand only allows the patient to move in a confined area determined by the path of the track in the ceiling. When the patient needs or wants to move beyond this area, he will need to carry his own IV bag or get assistance from a nurse who will accompany the patient, carrying the bag. Not only is this inconvenient for the patient and time consuming for the nurses, it also poses a safety hazard.

A patient in a hospital on intravenous is obviously in less than perfect health. Requiring this patient to carry the IV solution above their head is stressful and uncomfortable for the patient. There is also a risk the patient may lower the solution below the necessary height or even drop the container or fall. If a nurse must carry the patient's intravenous solution she must be sure to stay close enough to the patient to prevent pulling on the tube.

In order to decrease these safety hazards we decided our IV stand had to be mobile. However, as mentioned earlier, there is not sufficient space in the hospital room to accommodate traditional mobile, free-standing IV stands. A new design is clearly needed to achieve all desired functions.

In addition to added safety, a new IV stand design can possibly save the hospital money and reduce the required amount of storage space taken by unused stands. It does not seem reasonable for a hospital to purchase three separate pieces of equipment to perform the simple task of supporting and IV bag, but this is what is necessary to satisfactorily accomplish each of the design requirements.

The hanging IV stand is used while the patient is in bed. This design uses no floor space, it cannon be knocked over, and it has very simple height adjustment. The hospitals felt it suited their needs best. Our decision matrix (see section 4.1.7), based on background research and hospital visits, confirms this since the hanging design wins significantly over the free-standing designs. Despite the superiority of the hanging stand in many areas, the free-standing design allows patients to move easily and safely on their own while the hanging design does not. Likely because of their size and price, the hospitals have very few, if any, of these stands available. Finally, there is the third type of IV stand which attaches to the hospital bed for transferring patients in bed. This stand remains useless in storage at most times.

Based on all of the desired functions and features, we created a preliminary design that will accomplish all the tasks as simply and effectively as possible. Our initial design idea is shown in Figure 7. The hanging IV stand is the center of the design. However, the bottom portion of the hanging IV stand will be modified to fit in a hole in the hospital bed, eliminating the need to keep the extra stands in storage. Additionally, this bottom portion will also fit into the free-standing, mobile IV stand when necessary, to provide safe, comfortable patient mobility. The connections between all parts will be very simple to use, yet secure. This single product should perform as well, or better than each of the three IV stands currently used.

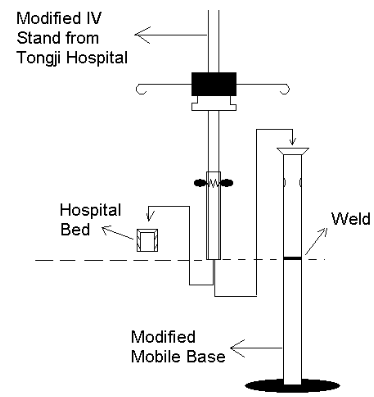


Figure 7: Preliminary Design

3.2 Part Design/Selection

After determining the basic design idea of our IV stand, we had to begin designing the individual components necessary to make it work. Each design parameter of each part was studied in detail to determine the optimal design with the best performance. The major components we needed to design were the base, the lower pole, the connection between the lower and upper sections, the height adjustment mechanism, and the upper pole.

3.2.1 Base

There is a huge variety of bases currently in use for free-standing intravenous stands. There are several parameters which affect the performance of a base design. The most obvious difference between many bases is the number of legs. This feature affects stability, maneuverability, and cost. Most IV stands are either four or five legs, although there are a few with three or six legs. Intuitively, one would assume that more legs lead to greater stability. This may or may not be true, depending on other features of the base, particularly the length of each leg.

Figure 8: Base Designs

However, more legs can result in greater material and manufacturing costs. First, each leg requires a caster, which immediately drives up the price of adding a leg. More material must be used to build an additional leg, further increasing cost. Manufacturing methods can also change depending on the number of legs. The four-leg base shown in Figure 8 is made from two pieces of bent metal, while the five-leg base is a single cast piece. This offers a price advantage to the five-leg base because casting is a less expensive process in a mass produced product.

The length of each leg is extremely important to the design of a base. As mentioned, it is a determining factor in base stability. It is also important to the comfort and ease of use of the IV stand. When a patient is rolling the IV stand with him it must be held far enough from his body as to prevent stepping on or tripping over the base. Longer legs will require the patient to hold the IV stand further away, making it uncomfortable to use.

The two designs in Figure 8 also differ in locating the center of gravity. The four-leg base is designed to keep the center of gravity as low as possible. The five-leg base makes less effort to lower its center of gravity. The center of gravity of the base is less important than the center of gravity of the stand as a whole. The five-leg base comprises a large portion of the total mass of the IV stand, thus keeping the overall center of gravity very low without an added feature (cost, complexity) to further lower the center of gravity. The four-leg base is significantly lighter, so as much weight must be as low as possible in order to lower the center of gravity of the entire stand.

Obviously there is no single design which optimizes every design criteria simultaneously, but by studying existing designs based on these parameters, we determined which option offers the best compromise.

3.2.2 Lower Pole

The lower pole needs to perform the functions of connecting securely to the base and to the upper connecting mechanism. It also must satisfy a certain height requirement, which will be based on the length of the upper pole and the desired height of a table, and be strong enough to safely support the expected loads.

The intravenous solution should always be approximately one meter above the level of the injection point, usually in the hand. This will be a major deciding factor in the chosen lengths of the poles. According to our research, the range of adjustment of a free-standing IV stand is generally from 120 to 200 centimeters. In order to achieve this range of motion with our design, we will need to consider the design of the upper and lower poles, the connection section, and the height of the base together. However, according to our design plan we know that the lower pole can not be taller than 120 centimeters from the ground when connected to the base, or the height adjustment won't be able to achieve the desired range.

The link between the base and the lower pole is a common bolt connection. This connection is simple, safe, and secure. There is no need to improve on this portion of current designs. The lower tube design ends where the upper connection portion begins, which will be welded to the top of the lower tube.

3.2.3 Connection

The connection between the top of the lower tube and the bottom of the hanging section will need to be an original design. The design must allow the upper section to be quickly and easily connected and removed while also providing stability and security of the connection.

An added option on many IV poles is a small table or handle attached to the pole. Our design will accommodate a table, if desired, but will not require its inclusion. The ergonomically appropriate height of such a table was found to be approximately 120 centimeters, so we will place this table at the top of the lower pole.

3.2.4 Height Adjustment

Height adjustments on IV stands come in two basic varieties. Free standing IV-stands are composed of two poles. The hooks are on the top of the upper pole, which slides inside the lower pole. By sliding the upper pole further into and out of the lower pole, the height is adjusted. A screw goes through the lower pole, pressing on the upper pole when tightened with the attached knob, locking the upper pole into place.

The second type of height adjustment is the style used on the hanging IV stand. This height adjustment is an individual component, with the hangers attached directly to it. This piece is attached to the pole and slides up and down in order to adjust the height of the hangers. It can easily slide up at any time, but will support loads pushing down on it. In order to adjust the height downward, the lower section must be pulled away from the upper section.

Both designs can technically be used in our IV stand. Therefore a decision had to be made as to which design was better suited for our needs. The design currently used on hanging IV stands allows very easy height adjustment, while securely supporting the IV solution. The height adjustment and hangers can not come off the pole, nor can they ever slide freely down the pole. As soon as the adjusting mechanism is released, the entire piece locks into place. On the other hand, the free-standing height adjustment is slightly more difficult to use and does not automatically lock into place, which can raise a safety hazard if the adjustment screw is not sufficiently tightened.

Because of its ease of use and easy integration into our design, the hanging height adjustment mechanism was selected for our design. Although we had several opportunities to exam the design of the existing component, we were not able to disassemble the piece, or see the working parts of the mechanism. Therefore, we need to either design our own mechanism that will accomplish the same functions or purchase one of the existing height adjusters.

3.2.5 Upper Pole

The upper pole will be required to act like a hanging IV stand while the patient is in bed. It will need to easily connect to the lower pole (see section 3.2.3) and act as the upper pole of a free standing IV stand. Finally, it should be able to connect to the hospital bed for use when moving a patient in bed. Each of these functions will require specific design characteristics of the upper pole to achieve smooth transitions between its different uses.

In addition to these functions, the upper pole must also satisfy certain height and strength requirements. While hanging above the bed, the upper pole must be sufficiently long to be easily reached and used by the nurses. While the upper pole is attached to the bed, it must be sufficiently tall to support the IV solution one meter above the point of injection. Finally, when used with the mobile base, the height should be adjustable from 120 centimeters to 200 centimeters. Since the height adjustment can only slide along the upper pole, this pole must range from 120 centimeters or below to 200 centimeters or above when attached to the base.

The upper pole will require a hook at the top which can attach to the slider in the ceiling of the hospital room. This hook must be sufficiently strong to support any expected loads. The upper pole itself also must be strong enough to support the solution containers hanging from its hangers.

3.3 Low Fluid Alarm

The selected method for realizing the low fluid alarm function was with a small electronic circuit utilizing a photoelectric sensor which can detect the presence of fluid. Because the team does not specialize in electrical engineering, outside help was required.

There are two possible methods of achieving the low fluid alarm. The first method senses the drop frequency of drops of IV solution. When the frequency drops below a certain value, the alarm will sound. This offers the advantage of sounding the alarm at a selected time before all the IV solution is gone, giving the nurses time to respond.

The second method is to simply detect the presence or absence of fluid in the IV tube. This method is simpler, but it requires that all the IV solution is gone before the alarm will sound.

4 Results

The results of the IV stand project will consist of four parts. First will be the detailed analysis of existing IV stands. Next will be our original IV stand design. Third is a working prototype of our design. Finally, we will need to analyze our own design and compare it to existing IV stands in order to demonstrate its value to the hospital and patients.

An additional section of results will discuss the successes and failures of our alarm design.

4.1 Product Analysis

As mentioned in the methodology, the first step was to analyze all the background data we collected from our internet research and hospital visits. In order to accomplish this, we began by listing the performance features we felt were important to make a good IV stand. After we had all our ideas down, we talked to the nurses and patients at the hospitals to see if we missed anything. We also asked them to rank the performance features in order of importance. Using this information we assigned a weight to each performance measure; the more important it was to the patients and nurses, the more it affected the overall decision. Each performance measure is described below, with its relative value of importance.

4.1.1 Stability (30%)

Stability is the most important feature because it is directly related to safety. Stability refers to the ability of an IV stand to resist being knocked over. An IV stand that can be easily tipped over could injure the patient or bystanders. It will also interrupt the flow of the IV solution and be upsetting to the patients.

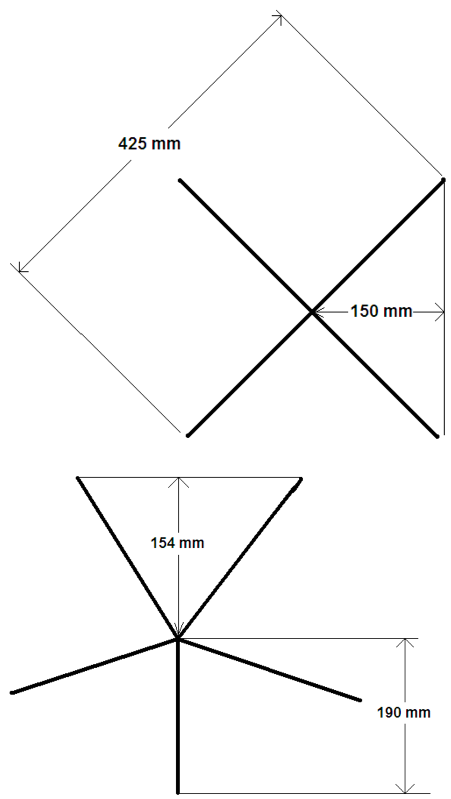


Figure 9: Stability Analysis Number of Legs

The main features affecting stability are the number and length of the legs and the height of the center of gravity. Figure 9 shows why a five-legged base is more stable than a four legged base. When the center of gravity of the IV stand leaves the base area, the IV stand will tip over. Therefore, the distance to the edge of the base area is a determining feature of stability. The four-legged base has legs of 212.5 millimeters and the shortest distance to the edge of the base area is 150 millimeters. The five-legged base has 190 millimeter legs. Despite the shorter legs, the extra leg makes the shortest distance to the edge of the base area 154 millimeters, and thus this design has greater stability.

The center of gravity also has an effect on the stability of the IV stand. A very low center of gravity will remain over the base area much longer after the IV stand begins to tip than a high center of gravity would. Therefore the low center of gravity is more desirable.

The one exception to this type of stability analysis is the hanging IV stand. This stand is the most stable because it can not be tipped over. It technically could come off of its hanger in the ceiling, but the hanger and hook are designed to make that very unlikely.

4.1.2 Maneuverability (20%)

Maneuverability refers to the ability of a patient on intravenous to move or be moved easily and comfortably. This feature is important to both the patients and the nurses. The patients desire the ability to move on their own. Simply using the bathroom is a major chore for patients without mobile IV stands. One would also assume it would be nice to be able to get out of bed and simply walk around for a short time, after lying in bed all day.

A mobile IV stand is also important to the nurses. It allows them to easily transfer patients. A mobile IV stand also frees the nurse to do other things while she would otherwise be accompanying a patient who wanted to get out of bed.

Judging maneuverability is more difficult than judging stability. Beginning with the obvious one, the hanging IV stand is the least mobile since it can only move in a very confined area. Based on information from the manufacturing professor, a four-legged base would make it difficult to change direction. Three or five legged bases are more maneuverable. Finally, some sort of handle or table can make it easier to grip and move an IV stand.

4.1.3 Ergonomics (20%)

Ergonomics refers to the comfort of the interaction between the user and the product. In this case, both the patient and nurse are considered the users of the IV stand. Ergonomics are very important to a large, top tier hospital such as Tongji. The patients are paying a large amount of money to be at a high quality hospital, so they expect the most comfortable, most pleasing, best equipment available. High quality equipment will ensure a comfortable setting and a pleasant visit (as pleasant as a hospital visit can be).

Not only will proper ergonomics result in patient comfort and satisfaction, it will also benefit the nurses. Ease of use of all the features will reduce the required effort, thus saving the nurses time and energy. Happier patients and more productive nurses is the overall result of good ergonomics.

Ergonomics is not an exact science which makes it one of the most difficult performance measures to judge. We assigned points for extra features, such as a table or handle. We also did our best to determine the ease of use and comfort level provided by each design. This included things like the height adjustment mechanism and the appearance of the product.

4.1.4 Easiness of Realization (10%)

Easiness of realization is an important factor of a design and depends on the complexity of manufacturing the product. Beyond the other performance measures, easiness of realization is a major determining factor in the likelihood of a product being produced. If a product can be produced simply and with existing equipment the product will be less expensive to begin producing and be more quickly brought to market. An easily realized product represents a smaller financial risk to the producer, which improves its chance of being mass-produced.

For the products investigated, most are already in production which means they have been realized. However, we ranked them based on the assumption that we would begin a new factory, and therefore do not have the equipment or manufacturing techniques determined yet. In this category, simple designs got the highest scores. Also, a cast base was ranked higher than a bent metal base since casting is a easier process for mass production.

4.1.5 Easiness of Dismantling (10%)

This feature of a design will determine its servicing costs. When a single part needs to be replaced on an easily dismantled IV stand, it can be quickly and inexpensively replaced by purchasing the single desired part and easily installing it. If the IV stand was not easily dismantled, this single broken part might keep an IV stand out of service for a long time, or possibly forever if the difficult process of replacing the part is not deemed worthwhile.

Easiness of dismantling will also simplify common tasks, such as transporting and cleaning the IV stand. Finally, an easily dismantled IV stand might even facilitate the recycling of used parts from IV stands as replacement parts on new IV stands.

The number of parts and complexity of the mechanisms were the determining factor in this category. Single piece, cast bases are ranked higher than multiple piece bases. Complex height adjustments, such as on the hanging IV stand, resulted in low scores.

4.1.6 Cost (10%)

While it initially seemed that cost would be one of the primary criteria for a good design, we learned on our hospital visit to Tongji that cost is a minimal concern. As mentioned in section 4.1.3, the patients pay a large amount of money to be at Tongji and therefore expect the best equipment. Therefore, Tongji is more concerned with getting the best equipment than saving money.

Cost is determined by the material and manufacturing processes of the product. It is also determined by the number of products the hospital would be required to purchase to have a sufficient supply of IV stands and mobile bases. This latter criterion is somewhat irrelevant for existing designs, but will become an important feature of our original design.

4.1.7 Decision Matrix

Using these six performance measures, we created a decision matrix to investigate the strength of the IV stands currently produced. Each stand was assigned a score ranging from one to five for each performance measure. These scores represent the relative performance of each design to the others. For example, for stability, the hanging IV stand got a five since it is nearly impossible to knock down. The five-legged stand got a four because it is more stable than the three or four-legged designs, but less stable than the hanging IV stand.

After scores were assigned to each stand in each category, the total score was determined based on the assigned weights of each performance measure. A portion of the decision matrix, with the highest scoring designs, can be seen in Figure 10, and the entire table can be found in Appendix A.

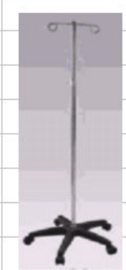
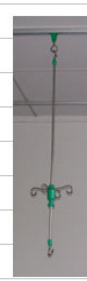
Design			
Safety (30%)	4	4	5
Maneuverability (20%)	3	5	1
Ergonomics (20%)	2	5	5
Easiness of Realization (10%)	4	1	5
Easiness of Dismantling (10%)	5	1	2
Cost (10%)	2	1	5
Total Score	66	70	78

Figure 10: Decision Matrix

As you can see, the hanging IV stand received the highest total score. This was expected since the hospital selected the hanging IV stand to be used in their hospital. Although it received the highest overall score, the hanging IV stand has the lowest score for maneuverability. Therefore, our original design will attempt to maintain the advantages of the hanging IV stand while also adding an option for mobility.

4.2 Original Design

Our basic design idea was described in section 3.1. Here we will describe the process of completing the design, piece by piece. A condensed version of the design process can be seen in matrix form in Appendix B, created to relate each component's features to the performance of the IV stand.

4.2.1 Base

Base designs were described in detail in section 3.2.1. The five-legged cast base was deemed the best due to its increased stability, short legs, and heavy weight (keeping the center of gravity low). Based on our resources and capabilities we concluded that we could not construct this style base on campus. We had a choice to construct the simpler four-legged base or purchase a five-legged base. In the end, purchasing the base was selected as the better option.

4.2.2 Lower Pole

By choosing to purchase the base, we found that we had to purchase an entire IV stand. This turned out to be very convenient since we simply used the included lower pole. Although the lower pole was slightly shorter than we desired to properly place the attachable table, we found the lower table was comfortable and convenient. Additionally, the lower table keeps the center of gravity lower, allowing greater stability.

4.2.3 Connection

Unlike the first two parts, the connection could not simply be purchased. It is our original design and so had to be manufactured on campus. Our connection consists of one piece welded to the top of the lower tube, a second piece welded to the bottom of the upper tube, and a locking mechanism. The top piece slides inside the bottom piece, and sits on a solid plate. The upper tube can then be rotated until it locks in place.

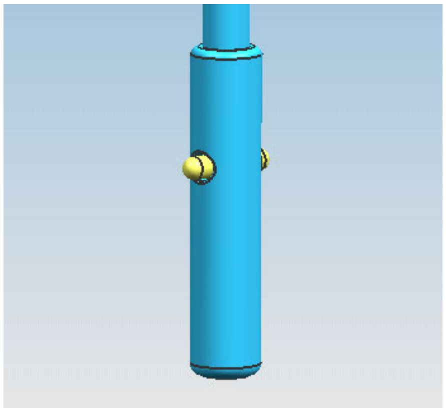


Figure 11: Connection - Upper Tube

Figure 12 shows the lower portion of the connection. The ring near the bottom is where the connection is welded to the lower tube. It is also the location of the solid plate which the upper tube sits on. To construct this, we plan to cut off a small portion of the lower tube, insert the plate, and welded the pole back together. The hole in the connection piece is where button of the locking mechanism pops out. At the very top of this piece is a small flange which guides the upper tube in, as well as compresses the button of the locking mechanism automatically, simplifying the connection process.

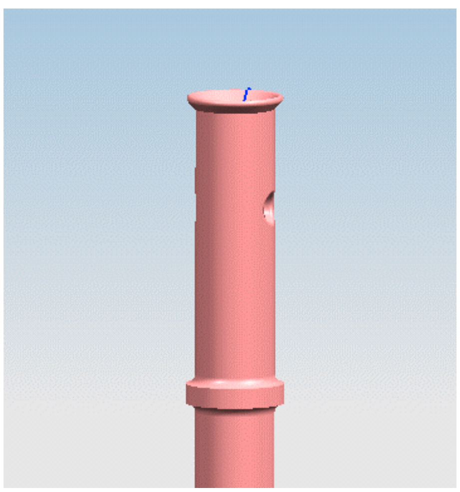


Figure 12: Connection - Lower Tube

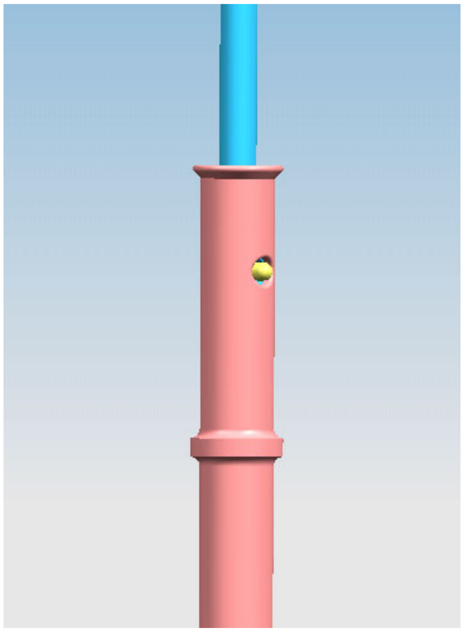


Figure 13: Connection - Connected

The upper portion of the connection is shown in Figure 11. The hanging portion of the stand is very thin, so a larger tube had to be welded to it. We plan to use a small section of the upper tube from the free-standing IV stand. This was convenient because the tube is of perfect diameter to fit snuggly inside the lower tube.

Figure 13 shows the two pieces connected. The small buttons protruding from the holes is the locking mechanism. The two buttons are connected by a spring which can be compressed and pushed entirely inside the tube when connecting the pieces together. After the two pieces are put together and the buttons are lined up with the holes on the lower tube these buttons extend again, locking the two pieces together. To separate the two pieces, simply push the two buttons inside again and lift the upper pole out.

4.2.4 Height Adjustment

Because we could not see the working part of the height adjustment on the hanging IV stand, we created our own design. Our preliminary design idea on how to accomplish the desired functions is shown in Figure 14. The vertical line represents the upper pole. The upper section, with the hangers, is pulled down over the cone shaped object, squeezing the piece against the pole, causing enough friction to hold the assembly in place. When weight is added to the hangers, the upper section is pushed down harder, squeezing the cone harder, and thus increasing the friction. Therefore, the hanger can not

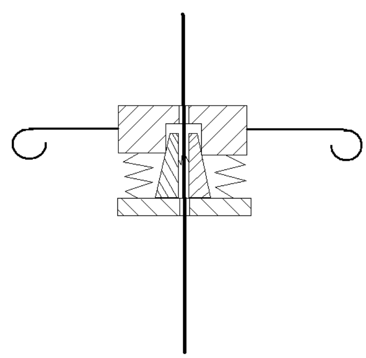


Figure 14: Preliminary Height Adjustment

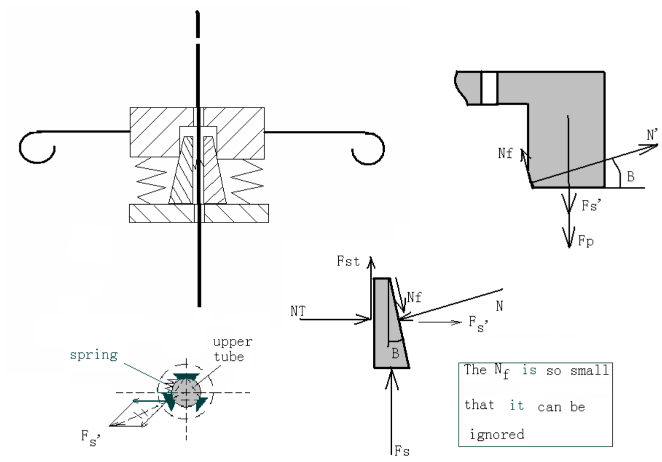


Figure 15: Height Adjustment Force Analysis

be forced down without purposely releasing the tension. To do this, the lower section is pulled downward. This allows the cone to expand, eliminating friction and allowing easy adjustment.

Because we were designing this entire mechanism, there were several parameters we needed to calculate in order to ensure the height adjustment would work as we desired. The first step in our analysis was to do a force analysis on the mechanism, as shown in Figure 15. The complete calculations can be seen in Appendix C. By doing this, we were able to determine the tension necessary in the springs in order to create sufficient clamping force to hold the overall structure in place, based on the materials selected and the angle of the cone. The equation in Figure 16 displays the governing equation for determining the minimum required spring force.

$$F_s \geq F_P\left(\frac{tg\theta}{f_{st}} - 1\right)$$

f --safety modulus > 1 ;

f_{st} -- friction modulus between tube and clamp ;

F_P -- the overall pull outside ;

Figure 16: Required Spring Force for Height Adjustment

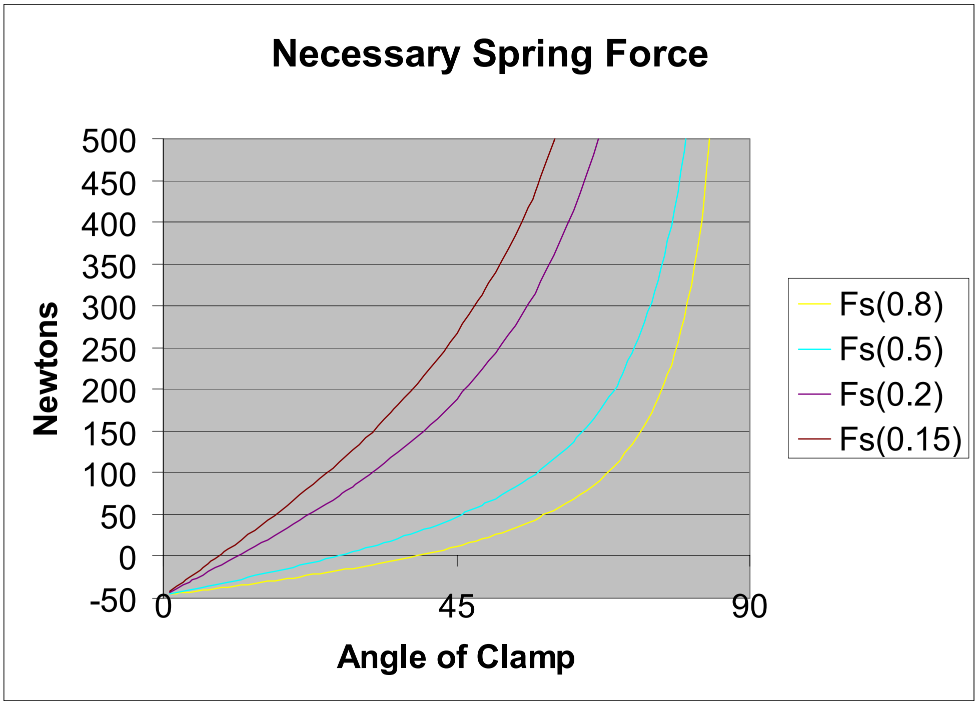


Figure 17: Required Spring Force as a Function of Clamp Angle and Friction Coefficient

After deriving this equation we were able to select the parameters for our design and solve for the spring force to see if it is a reasonable value. A graph relating all the relevant variables can be seen in Figure 17 below. The angle of the cone is on the x-axis while the required force applied by the springs is on the y-axis. Each line represents a different coefficient of friction, which will depend on the selected material. The higher the coefficient of friction is, the less the spring force has to be. With regard to the relationship to the angle of the cone inside the clamp, small angles provide a large mechanical advantage, requiring little or no tension in the springs to produce the required friction. However, using very small angles will require a long motion to create sufficient separation of the cone from the upper piece to allow adjustment.

Material of the clamp	Friction modulus between tube and clamp : f_{st}	Safety modulus: f	Overall supported weight: F_p (Newtons)	Angle of the clamp: θ (°)	Necessary force of the springs: Newtons $F_s > F_p * (\tan\theta/f_{st} - 1)$	Distortion measure: Δx (mm)	The elasticity modulus of the spring outside : $K = F_s / \Delta x_1$
Metal-rubber	0.8	1 .2	47.04	30	<0	20	149
				45	11.76		
				60	54.80		
Metal-metal	0.15	1.2	47.04	30	134		
				20	67		
				10	8.25		

Figure 18: Height Adjustment Spring Selection

By selecting an intermediate angle of 30 degrees and a rubber—metal contact with a friction coefficient of 0.8, we were able to keep the required spring force below zero. This means that the weight of the upper portion of the IV stand is sufficient to keep entire part in place on the pole. It also required a minimal separation of the two pieces in order to allow adjustment. Despite the theoretical negative spring force required, we decided to apply a small tension to the spring in the fixed position.

The tension initially in the spring needs to be overcome by the user when the height is to be adjusted, so this force should be kept within proper ergonomic values. By using a small force gauge, we were able to determine that even the smallest individual could apply approximately 20 Newtons of force to this type of mechanism with a single hand. We selected 6 Newtons as the initial force applied by the spring, and 12 Newtons as the maximum force required to be applied by the user to cause a separation of 20 millimeters between the two pieces, thus allowing an easy adjustment. The calculations shown in Appendix D explain the process of selecting a spring that will conform to these requirements. Ultimately, it was determined that a stainless steel spring will require a free length of 33 millimeters and a spring constant of 0.149 N/mm.

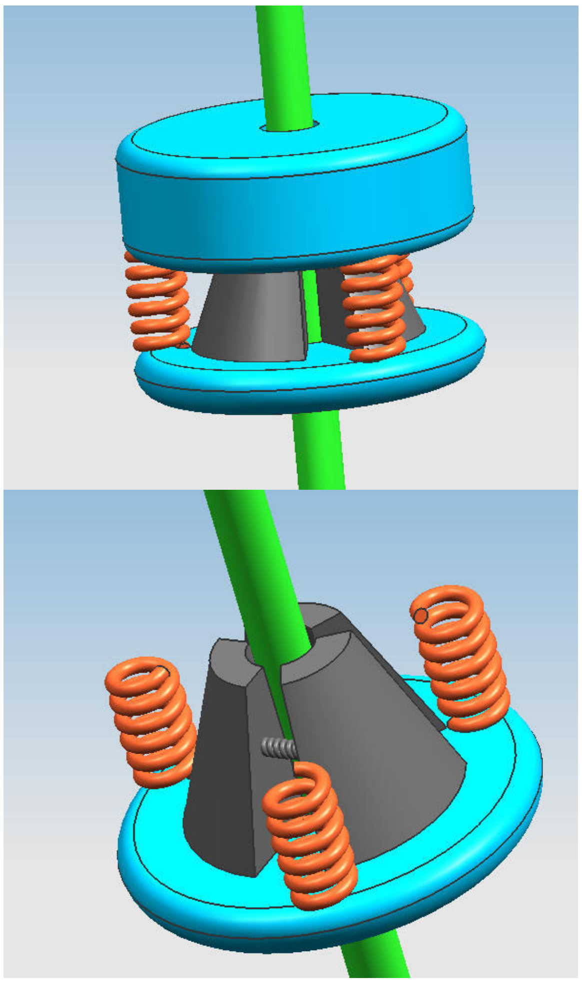


Figure 19: Height Adjustment Model

The first picture in Figure 19 is the completed height adjustment mechanism (without any case or cover). The second picture provides a better view of the internal parts of the mechanism. The three pink springs will be in tension, pulling the top and bottom blue pieces together. The three black cone sections will squeeze against the green pole to hold the height adjustment in place. The small spring between the black pieces will be very weak, but will assist in separating the black pieces from the pole during adjustments.

4.2.5 Upper Pole

The upper pole is the central component of our design. It will be used in each of the three different functions of our system. Despite its importance, it is still simply a pole. Since the upper pole will be a hanging IV stand most of the time, and the existing hanging IV stands are so highly rated, we essentially copied the existing hanging IV stand design. We had to ensure the current length satisfied the height requirements when used with the mobile base or with the bed. Another consideration was the diameter. A larger diameter will be heavier and a smaller diameter might not be strong enough. Again, we decided to go with what we know works, and make it the same diameter as the existing hanging IV stand.

4.3 Prototype

Figure 20: Completed Prototype

After the design was complete, we needed to decide how to go about manufacturing our IV stand. As mentioned above, we purchased a free-standing IV stand with a five-leg base. After some deliberation, it was decided that the height adjustment mechanism could not be manufactured quickly or inexpensively enough. Therefore, we also purchased a hanging IV stand.

We received the two items and brought them to the factory along with our engineering drawings of the connection and table. A few days later we returned to get the completed IV stand. The workers altered our connection design slightly for easier manufacturing, but the overall function was identical. Also, we were informed that the table could not be attached to the IV stand how we wanted it. Unfortunately we did not have time to redesign the table, but it is a minor point of our overall design. Additional pictures of the individual components can be found in Appendix E.

4.4 Design Validation

After creating this design and manufacturing the prototype, we needed to prove that the effort was worthwhile and the design was valid. A good indicator of the strength of a design is how well it achieves its goals. The goal of this project was to design an IV stand that could accommodate patients while in bed and while out of bed, and that is exactly what this IV stand will do.

A more analytical method of determining the strength of our design is by showing that our design performs better than existing designs through the use of our decision matrix. This will give a side by side comparison of our design compared to others.

Design				
Safety (25%)	4	4	5	4
Maneuverability (15%)	3	5	1	4
Ergonomics (15%)	2	5	5	4
Versatility (15%)	2	2	2	5
Easiness of Realization (10%)	4	1	5	3
Easiness of Dismantling (10%)	5	1	2	4
Cost (10%)	2	1	5	3
Total Score	63	62	73	79

Figure 21: Updated Decision Matrix

The updated decision matrix shown in Figure 21 has a new criterion, as well as the new design. The strength of our new design is in its ability to perform several functions. Each of the other designs performs their single function admirably, but only that single function. Therefore, a versatility score was added, in which our design has the highest score. This results in a higher score for our design than any of the existing designs.

In comparison with existing designs, our original IV stand offers advantages to both the patients and the nurses. This design provides the same simple and comfortable functions as the original hanging IV stand, which is well like by the patients and the nurses. The mobile base also provides the patient with mobility beyond the reach of the hanging IV stand. The patient will feel less confined and be less dependent on the nurses for assistance. He will be able to walk to the bathroom or to a sitting area on his own, without having to carry the IV solution over his head. Not only will this make the patient's stay more enjoyable, it will allow the nurses to dedicate their time to more important tasks worthy of their training.

Finally, the ability of the hanging portion of our design to attach to the hospital bed will simplify the transfer of a patient while in bed. The hanging portion needs only be taken off the ceiling hook and placed in the hole in the bed frame. The IV solution can even be left on the same hook; the height adjustment can be raised to its highest position, providing sufficient height of the solution.

4.5 Alarm

The design of the alarm is heavily dependent on knowledge of electrical engineering. Unfortunately, the team possessed little of this required knowledge. However, through our own efforts and with help from others, we were able to assemble two alarm circuits.

4.5.1 Alarm 1

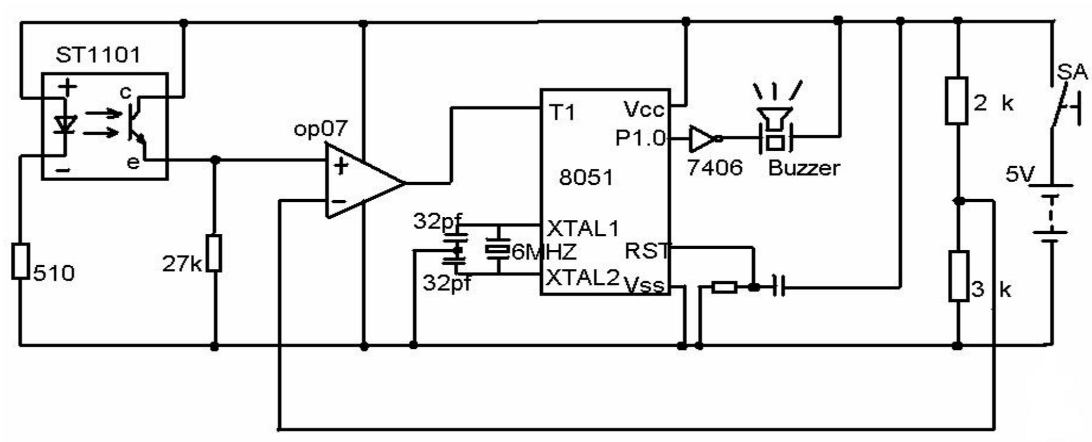


Figure 22: Alarm Circuit 1

Our first alarm is based on the fact that the frequency of drops from the IV container will decrease as the content of the bag diminishes. Therefore, it would be possible to tell when the level of the solution has reached a critically low level by counting the frequency of the drops. This circuit shown in Figure 22 basically does this. The drops flowing past the photoelectric sensor result in a oscillating voltage. This voltage is fed into a chip which has been programmed with our original code, and when the frequency of oscillations becomes too low, the chip activates the buzzer.

Testing our circuit design and program code on computer simulations resulted in positive results, but when the circuit was actually built it did not perform quite as well. The photoelectric sensor was not sensitive enough to clearly detect the drops of liquid.

4.5.2 Alarm 2

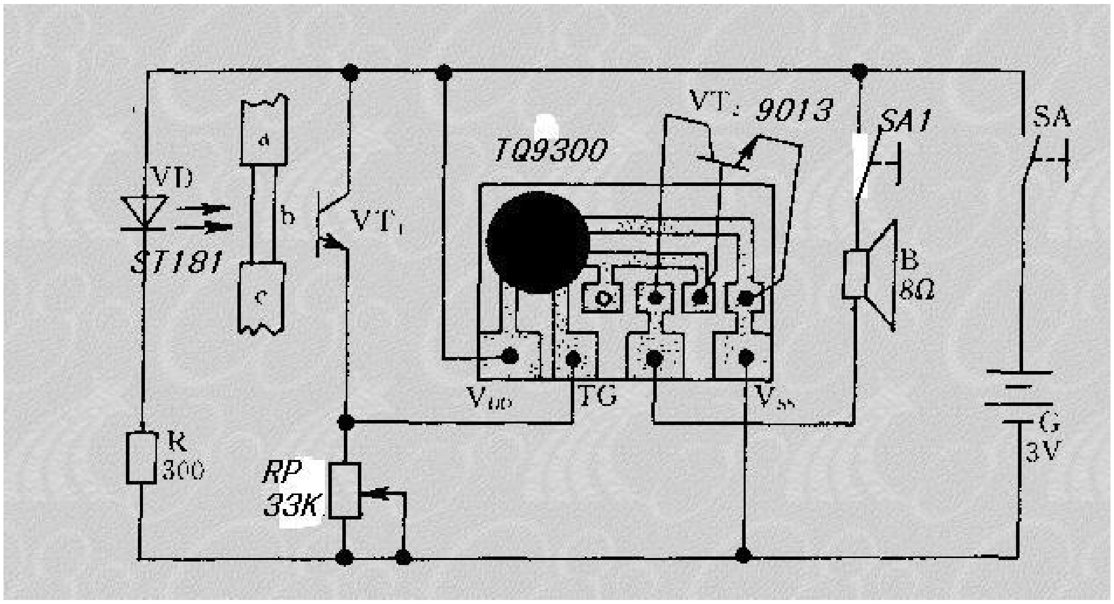


Figure 23: Alarm Circuit 2

Our second alarm design takes the simpler approach of detecting the presence or absence of fluid in the tube. When the fluid is gone, the buzzer is triggered and the alarm sounds. Again, the sensitivity of the photoelectric sensor caused a problem. The sensor did not send a strong enough signal to trigger the buzzer when a clear fluid was used in the tube. Therefore, this alarm could only be used with colored fluids.

5 Conclusion

Completing this design for Chinese hospitals while in China allowed us to create a design specifically to meet their needs. By visiting the hospitals, requirements specific to Chinese hospitals were discovered which could not have been realized otherwise. For example, the need for six beds in each hospital room is quite different from American hospitals, where there are usually one or two. This simple observation significantly altered our design plan.

After completing the project, we can conclude that the IV stand design is good. However, after seeing the prototype, we can also conclude that it can be better. One factor we did not consider thoroughly enough was the rigidity of the upper pole. By reusing the existing hanging IV stand as our upper pole, the pole was too thin for our application. It swayed significantly while it was attached to the lower pole. Using a slightly thicker upper pole would solve this problem, but it would also require manufacturing a new height adjustment mechanism that will fit on the larger pole.

Throughout this project we have been evaluating IV stands based on the designed features and functions. However, a good measure can not be made without a hands-on test of several IV stands. Many factors not related to the design can affect the final product. This was one of the downfalls of our IV stand. Although the idea is valid and the design is promising, the prototype did not meet our expectations. The quality of the free standing IV pole we purchased was poor. The base was not level on its wheels causing instability. The wheels barely rolled at all, making maneuverability very difficult. The most obvious flaw of our prototype is the lean of the completed pole. This is not caused

Figure 24: Bent lower pole

by any design criteria but by poor manufacturing of the lower pole. You can see in Figure 24 the slight bend in the lower pole, right near the attachment with the base. Although it appears small, this bend causes an obvious lean in the completed IV stand.

Overall, it is felt that the concept has potential for benefiting hospitals and patients in China. However, we suggest further work is done to remedy the above mentioned issues. It is also recommended that the next prototype is manufactured completely in house to better control quality.

6 Bibliography

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HUST Hospital. Nurse and patient interviews.

7 Appendices

Appendix A

We investigated several different existing IV stand designs. In order to determine the best designs, we created a table listing the features of each. We then determined the criteria for rating an IV stand and the importance of each. Each stand was rated in each category, and a final score is calculated, considering the score and associated weight for each category. As you can see, the hanging IV stand, design 6, received the highest final score.

	1	2	3	4	5	6
Base Material	Stainless Steel	Cast Iron	Stainless Steel	Stainless Steel	Plastic with Rubber Wrap	Hanging
Lower Tube Material	Stainless Steel	Stainless Steel	Stainless Steel	Stainless Steel	Stainless Steel	
Upper Tube Material	Stainless Steel	Stainless Steel	Stainless Steel	Stainless Steel	Stainless Steel	
Lower Tube Length	approximately 120 cm	approximately 120 cm	approximately 120 cm	approximately 120 cm	approximately 120 cm	
Upper Tube Length	approximately 80 cm	approximately 80 cm	approximately 80 cm	approximately 80 cm	approximately 80 cm	
Height Adjustment	Pressure Screw	Pressure Screw	Pressure Screw	Pressure Screw	Unknown	
Number of Casters	4	5	3	3	5	
Number of Hangers	2	2	2	4	2	5
Accessories	None	None	None	Small Table	Table, Cable Organizer	
Design Number	1	2	3	4	5	6
Safety (30%)	3	4	1	1	4	5
Maneuverability (20%)	2	3	3	4	5	1
Ergonomics (20%)	2	2	2	3	5	5
Easiness of Realization (10%)	5	4	4	3	1	5
Easiness of Dismantling (10%)	4	5	5	3	1	2
Cost (10%)	3	2	4	2	1	5
Total Score	58	66	52	50	70	78

Appendix B

The design process required the consideration of many factors. Each design feature affected multiple areas of performance. In order to elucidate the complex relationships, the following design tables were created. Each feature of each component of the IV stand is examined in detail. Different options were considered, and their effect on the performance measures was determined. By doing this, we were able to determine the best combination of features for our design.

			Stability	Ergonomics	Maneuverability	Realization	Service	Cost	Conclusion
Base	Number of Legs	3	Poor (small base area)		Good	Good (available for purchase)	Good (single part, less to clean)	Good (Casting is less expensive)	The 5 leg base requires the shortest legs for sufficient stability, and is reasonably inexpensive to manufacture , Its weight keeps the center of gravity of the stand low and stable.
		4	Average		Poor	Good (available for purchase)	Poor (2 pieces)	Poor	
		5	Good (large base area)			Poor (difficult to build or find to purchase)	Average (1 piece but more legs to clean)	Good (Casting is less expensive)	
	Center of Gravity	Normal	Average			Good		Good	
		Low	Good			Average		Poor	
	Wheels	Yes	Average		Good	Good	Poor	Average	
		No	Good		Poor	Good	Good	Good	
	Length of Legs	Long	Good	Poor	Poor				
		Short	Poor	Good	Good				
	Weight	Heavy	Good	Average			Poor		
		Light	Poor	Good			Good		

			Stability	Ergonomics	Maneuverability	Realization	Service	Cost	Conclusion
Lower Pole	Diameter	Small	Poor					Good	The length will be determined by the length of the upper pole and connection section. The diameter will be the standard size of normal IV stands.
		Large	Good					Poor	
	Length	Long	Poor	Average	Poor			Poor	
		Average (1 meter)	Average	Good	Good			Average	
		Short	Good	Poor	Poor			Good	

		Stability	Ergonomics	Maneuverability	Realization	Service	Cost	Conclusion
Connection	Original Design	The upper pole sits securely on a welded seat and locks into place with a simple spring/button mechanism	The two sections fit easily together. A flange on the lower pole automatically compresses the button when inserting the upper pole. It is easily removed with the push of a button.		It is a simple design, reusing the lower pole and a section of upper pole from an existing IV stand.	Easily disassembled, few moving parts	Very inexpensive, easily fabricated, no complex machining or difficult new designs	This design is simple, effective, and safe.

			Stability	Ergonomics	Maneuver.	Realization	Service	Cost	Conclusion
Height Adjustment	Original Design		Good, the heavier the load is, the stronger the gripping force is.	Good, simple, one-handed adjustments		Average, fairly difficult for us to manufacture but simple design for large-scale production	Good, Easily disassembled with replaceable parts	Good, can be inexpensive on large scale production, simple solid parts and a few springs	Although our original design is worthy, we are force to select the existing design from the hanging IV stand due to manufacture and time concerns
	Existing Designs	Free-Standing	Average, can be dropped or fall from height	Poor, not easy to use, requires two hands and a fair amount of strength		Good, very common	Poor, unreliable and not easily fixed	Good, single screw	
		Hanging	Good	Good, simple, one-handed adjustment		Good, currently in use	Unknown	Unknown	

Appendix C

Our original height adjustment design involved a clamp over the upper pole, which is opened or closed by the weight of the IV hangers and containers. In order to go from the conceptual design to a working design, we needed to choose/calculate the variables. The following is the derivation of the equation relating the required spring force to the angle of the clamp, the friction modulus between the clamp and the upper pole, and the supported load.

$$\because \begin{cases} 3N\sin\theta = F_s + F_p \\ 3f_{st} + F_s = 3N\sin\theta \\ F_{st} \le N_T f_{st} \\ 2F_{s'}\cos 30° + N_T = N\cos\theta \\ F_p = fG_{bag} \end{cases}$$

f --safety modulus > 1 ;

f_{st} -- friction modulus between tube and clamp ;

F_P -- the overall supported load ;

$$\therefore\ 3F_{ST} + F_s = F_s + F_p$$

$$3F_{ST} = F_P$$

$$F_{ST} = F_P/3$$

$$N_T \ge \frac{F_P}{3f_{ST}}$$

$$\because\ N_T = \frac{F_P + F_s}{3\sin\theta}\cos\theta - 2F_{s'}\cos 30° \ge \frac{F_P}{3f_{ST}}$$

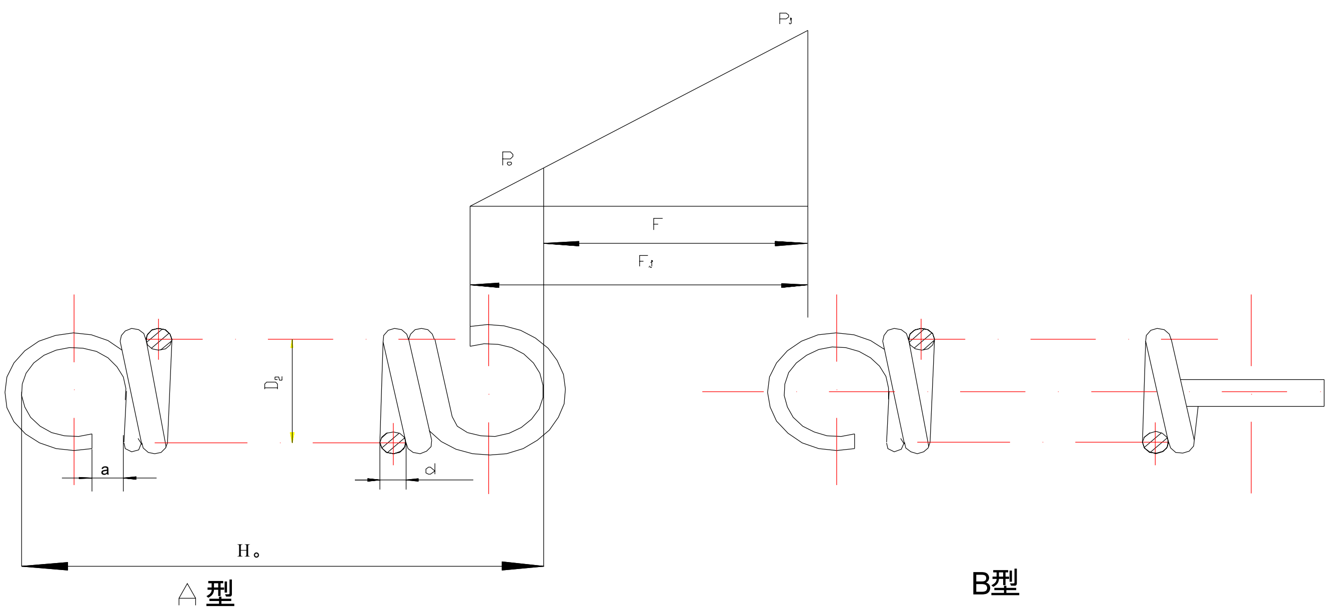
$$\therefore\ F_s \geq \frac{F_P(\sin\theta - f_{st}\cos\theta) + 6F_{s'}\sin\theta\cos 30^\circ f_{st}}{\cos\theta f_{st}}$$

If $F_{s'} = 0$

So $F_s \geq F_P(\frac{tg\theta}{f_{st}} - 1)$

Appendix D

The total required spring force was calculated in the previous appendix. This appendix uses the results to specify the particular springs needed in order to accomplish the desired affect. Since the force applied by a spring increases as it is stretched, the initial and maximum forces needed to be considered, based on ergonomic data, in order to ensure the product will not require much strength to use. The following derivation describes the process, from selecting the required force to the final spring design.



Minimum Fs < 0

We select Fs = 6 Newtons

Based on ergonomic experiments, we decide a person can apply 12 Newtons of force to the adjustment.

Choose F_s =6N, F_{people} =12N, choose stainless spring .

d=0.5 , D_2 =3.5mm ,G=71000MPa ,the whole circuit number n=58

• Process:

Known : $D \le 8$,working length $h = \Delta x$ =20mm(according to Ergonomics), kind I ,

$F_{\min} = F_s/3 = 2N$, $F_{\max} = F_{people}/3 = 4N$

Plan :

(1) choose C=8 due to C=D2/d=(D-d)/d ,choose d=0.5 mm spring , consult the table

σ_b =1570MPa[τ]=0.28 σ_b =439.32MPa

(2) calculate the diameter, d:

$$K=\frac{4c-1}{4c-4}+\frac{0.615}{c}=1.184$$

$$d \ge 1.6\sqrt{\frac{KF_{\max}c}{[\tau]}}=0.47mm$$

This value is similar to d=0.5, so we choose d=0.5mm is right.

So D_2=Cd =8*0.5=4mm<8mm

(3) calculate the number of the spring:

$$\lambda\max = h\frac{F_{\max}}{F_{\max}-F_{\min}} = 20\times\frac{4}{4-2} = 26.7mm$$

consult the table□G=71000MPa

$$\text{so , } n=\frac{G\lambda d}{8FC^3}=\frac{71000\times 26.7\times 0.5}{8\times 4\times 8^3}=57.8,$$

choose the whole number n_1=n=58

the length of the spring H_0=(n+1)d+D_1=59*0.5+4-0.5=33mm

(4) calculate the real modulus:

$$\lambda\max=\frac{8nF_{\max}C^3}{Gd}=\frac{8\times 58\times 4\times 8^3}{71000\times 0.5}=26.7$$

$$\lambda_{\min}=\lambda_{\max}-h=26.7-20=6.7mm$$

$$F_{\min}\frac{\lambda_{\min}Gd}{8nC^3}=\frac{6.7\times 71000\times 0.5}{8\times 58\times 8^3}=1.001N$$

Results:

$$K=\frac{F_{\min}}{\lambda_{\min}}=0.149N/mm$$

d=0.5 mm, D_2=3.5mm ,G=71000MPa ,the whole circuit number n=58

Appendix E

Pictures of the individual components of the prototype are shown below.

Figure 26: Lower Pole and Base

Figure 25: Connection

Figure 27: Upper Pole and Height Adjustment

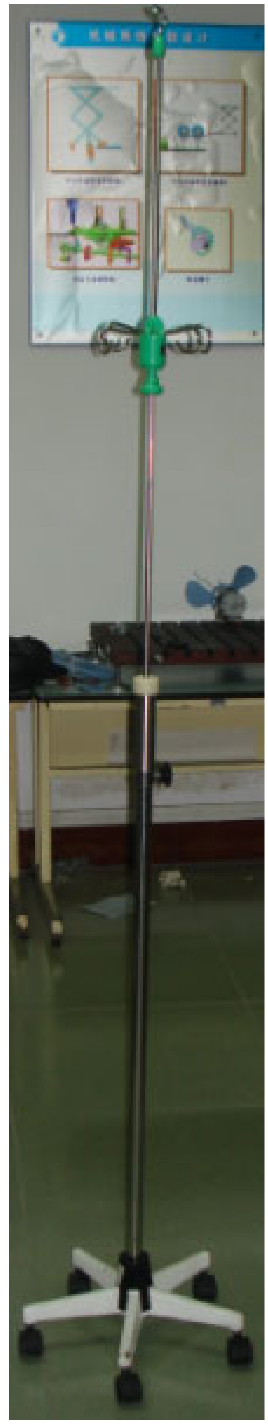


Figure 28: Complete assembly