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REVIEW ARTICLE

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FAILURE ANALYSIS OF PLATES USED IN TREATMENT OF PECTUS EXCAVATUM BY USING FEM

V. SIVA PRASAD[1], Y. VENU BABU[2]

[1]M.Tech, (CAD/CAM), Student, Department of Mechanical Engineering, Chirala Engineering College, Chirala.

[2]Associate Professor, Department of Mechanical Engineering, Chirala Engineering College, Chirala.

ABSTRACT

Pectus Excavatum is an abnormal development of the rib cage where the chest bone (sternum) caves in resulting in a sunken chest wall deformation. In this work, the stress analyses of different materials used in the treatment of Pectus Excavatum have been studied. Numerical Simulation is done using FEA (ANSYS) tool to predict stress of the Bio material.

Many Biomaterials exists in the market, in this work Ti-6Al-4V, Co-Cr-Mo and Cr-Ni-Mo material are taken for the analysis. In this work, the analytical and stimulated results of the given materials are compared and the best material has been found. The design optimizations also have been done for the plate and it has been redesigned for the patient concerned.

The materials are given with two different dimensions which suits both Indians and the people of United States as the survey says foreigners differ from Indians by 20% grater in broadness of chest bone. (Pectus).

Key words: Pectus Excavatum, chest bone (sternum), Finite Element Method, stress analyses, Numerical Simulation, Biomaterials, optimizations.

1. INTRODUCTION TO PECTUS EXCAVATUM

Pectus excavatum (PE) is an abnormal developed on the rib cage where the breastbone (sternum) caves in, resulting in a sunken chest wall deformity. Sometimes referred to as funnel chest, pectus excavatum is a deformity often present that can be mild or severe. Occurrence pectus excavatum is about 2% but surgical treatment is necessary for about 25% of patients. This type of deformation is almost 2 times frequency in boys than girls. In 1998 Donald Nuss introduced a new, minimally invasive technique of funnel chest treatment. Short hospitalization time and good temporary cosmetic result are doubtless advantage of this method. Implantation technique consists: general anaesthesia, selection of the proper length of the fixation plate and appropriate bent, incision of thoracoscope, insertion of clamp, insertion of bent plate and correction of deformation.

1.1. Causes of Pectus Excavatum:

The cause of pectus excavatum is not well understood. yet, researchers believe that the deformity is caused by excessive growth of the connective tissue(cartilage) that joins the rib to the breastbone also known as the costochondral region , which causes as inward defect of the sternum.

While the vast majority of pectus excavatum cases are not associated with any other condition, some disorder may include the sunken chest feature of pectus excavatum, marfan syndrome: A convective tissue disorder, which causes skeletal defects typically recongised by long limbs and spider like fingers, chest abnormalities, curvature of the spine and facial features including a highly arched palate and croweded teeth.

Rickets: A deficiency diease occurring primarily in children, rickets results from a lack of vitamin D or calcium and from insufficient exposure to sunlight, disturbs normal bone growth (Fig.1). (Adam)

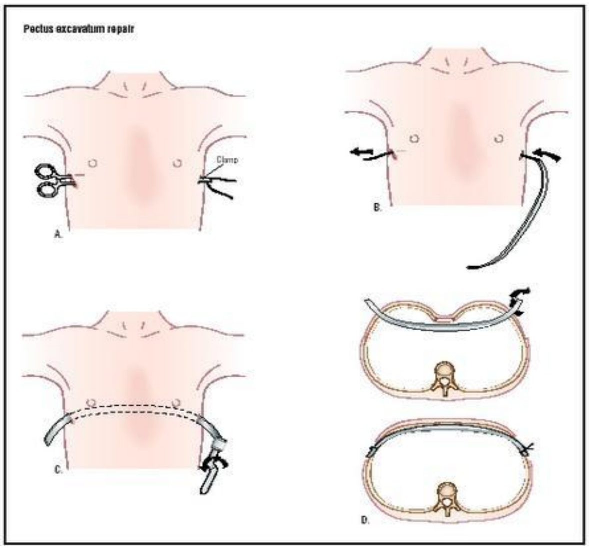


Fig No.1 Pectus Excavatum

1.2. Symptoms of Pectus Excavatum:

Most patients do not have symptoms, through a minority of patients may have the symptoms. (Fig.2 & 3)

1. Fatigue
2. Shortness of breath
3. Chest pain
4. Fast heart rate(tachycardia)

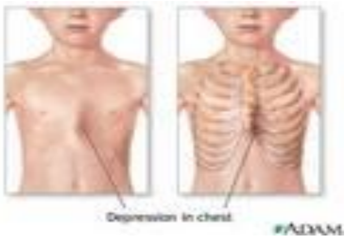


Fig No.2 Causes of Pectus Excavatum

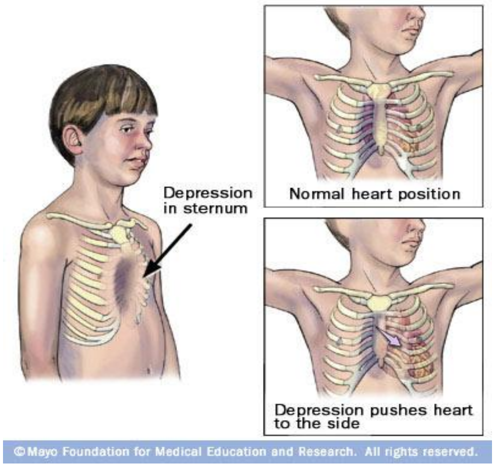


Fig No.3 Depression Model

1.3. Number of primary operations by age:

The age parameters for surgical correction depend on the type of procedure selected. Unlike the more invasive procedure (eg Ravitch procedure or sternal turnover) there is no interference with growth plates when using the minimally invasive procedure. There, it can be done at any age, as evidence d by the face that the authors have operated on patients from 21 months to 29 years of age successfully. The concern with patients younger than 6 years, however, is that if the procedure is done at too young age, there are many years of subsequent growth during which the pectus excavatum may recur as shown in fig.4.

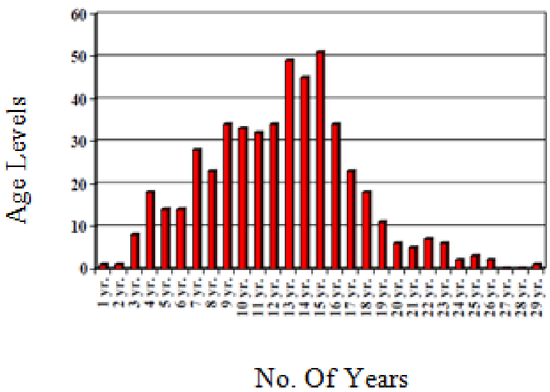
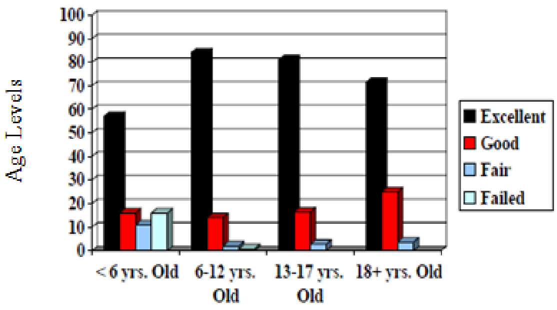


Fig.No.4. Number of Primary Operation by Age

The authors experience has shown that the optimal age 7 to 14 years, because, before puberty, the patient's chests are still soft and malleable; they show quick recovery, a rapid return to normal activities, and have excellent results. After puberty, the flexibility of the chest wall is decreased, requiring the insertion of two bars, making the procedure more difficult. It also takes the patients longer to recover. All of the author's patients over 20 year of age, however, have been extremely pleased with their results. Several other university centres have reported success with patients up to 44 year of age as shown in fig.5. (P. Colombani)



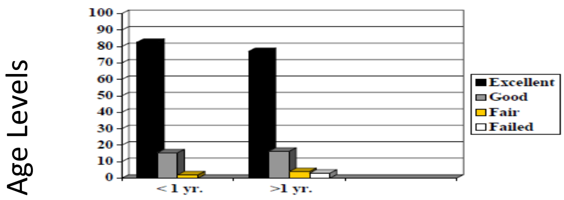
No. Of Years

Fig.No.5. Long Term Results by Age at Time of Surgery

1.4. Over Results and Long- Term Follow-Up:

Patients were followed at 6 months postoperatively, they then yearly. Long –term assessments classified the resolution of associated symptoms. A good repair is distinguished by a markedly improved but not totally normal chest wall appearance and resolution of associated symptoms. Fair results indicate a mild residual pectus excavatum without complete resolution of symptoms. A failed repair is marked by a recurrence of the pectus deformity and associated symptoms or need for additional surgery after final removal of the bar as shown in fig 6.

In addition, patients with EKG conduction abnormalities or mitral valve prolapse (MVP) had follow-up assessments. Patients old enough to have PFT studies were reassessed with repeat studies.



No. Of Years

Fig.No.6. Long Term Results by Time Since Bar Removed

1.5. Bar Removal:

The authors advise the pectus bar be left in place for 2 to 4years. The authors evaluate patients on an annual basis and monitor their growth, activity level, and PFTs, and encourage them to do their pectus excercise and participate in aerobic sports. Patients between the ages of 6 to 10 often do not grow rapidly.

Therefore, they tolerate the bar well for 3 or even 4 years. On the other hand, the authors have had teenagers who have had a massive growth spurt, growing 14 cm a year. They completely outgrow the bar and require bar removal after only 2 years.

1.6.Benefits of Pectus Excavatum Surgical Repair:

As compared with traditional surgery, patients who undergo laparoscope or minimally invasive surgery to repair pectus excavatum, such as VATS with the Nuss procedure, may experience:

1. Decreased postoperative pain
2. Shorter hospital stay
3. More rapid recovery and return to work

Other possible benefits include reduced risk of infection and less bleeding.

The highly modified Ravitch technique offers:

1. Shortened hospital stay following the procedure, rarely exceeding five days
2. Decreased postoperative pain
3. Reduced risk of complications

Risks of Surgical Repair of Pectus Excavatum:

The surgical repair of pectus excavatum, like other extensive surgical procedures, presents risks. While both the Nuss procedure and the modified Ravtich technique are safe and effective procedures, complication can occur. Possible complications from surgical repair of pectus excavatum include:

1. Pneumothorx (an accumulation) of air or gas in the pleural space)
2. Bleeding
3. Pleural effusion (fluid around the lung)
4. Infection
5. Bar displacement

Pectus excavatum recurrence (due to having the surgical correction completed too early prior to puberty and or not leaving the strut or bar in place for a long enough period). Recurrence is less likely after the Ravitch procedure.

2. Introduction to Finite Element Analysis:

Finite element analysis (FEA) is one of such numerical procedure for analyzing and solving wide range of complex engineering problems (may be structural, heat conduction, flow flied…etc) which are complicated to be solved satisfactory by any of the available classical analytical methods.

The computer intervention is the backbone of the procedure since it involves the solution of many simulation algebraic equations, which can be solved easily by the computer; actually finite element method was originated as a method of stress analysis. But today the applications are numerous. Now a days each and every design is developed through Finite Element Analysis.

2.1. Selection of Element:

The main step in the finite element analysis is choosing the right element because the assumption and formulation made in a particular element must represent the real structure behaviour in the model using solid 45 3D 8 node tetrahedral structures solid.

2.2. Element Description:

Solid 45 is a 3D 8 node tetrahedral structure solid .It has quadratic displacement behaviour and is well suited to modelling irregular meshes.

The type of problem i.e. shape, size and configuration is to be chosen beforehand. The number of elements is to be chosen such that they represent the entire geometry. The selection element depends on the type of the body and the number of independent coordinates necessary to describe the system. Three-dimensional elements can be used when the geometry and materials properties are described by three spatial coordinates. The basic three-dimensional element is the tetrahedron element as shown in fig.7.

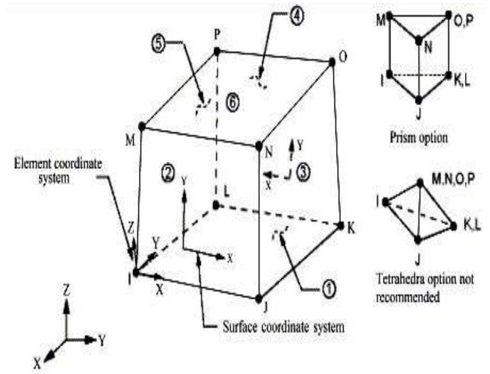


Fig.No.7. Solid 45 is a 3D 8 Node Tetrahedral Structure Solid

3. Materials Properties of Fixation Plates

3.1 Biomaterials

Biomaterials can be defined as in organic or inorganic materials that are biocompatible and can be implanted in the human body to replace or repair failing tissue. The concept extends to the materials used in drug-delivery system. Biosensors or devices operating outside the body but in communications wiyh it-for example. The haemodialyser for patients with kidney failure.

Areas covered also include vascular graft materials. Dental and ocular materials, cartilage, joint, tendon, liagament and soft tissue replacements for biomaterials and drug- delivery systems.

1. Stainless steel alloy
2. Cobalt-chrome alloy
3. Titanium alloy
4. Composites

3.2. Comparison of Characteristics of materials:

TABLE-1

Characteristic	S-Steel	Co-Cr alloy	Titanium Alloy
Stiffness	High	Medium	Low
Strength	Medium	Medium	High
Corrosion-resistance	Low	Medium	High
Biocompatibility	Low	Medium	High

TABLE-2

BIOMATERIAL	t, (mm)	l,(mm)	F,(N)
Stainless Steel Cr-Ni-Mo	2.5	150	430
Ti-6Al-4V	2.5	150	555
Co-Cr-Mo	2.5	150	595

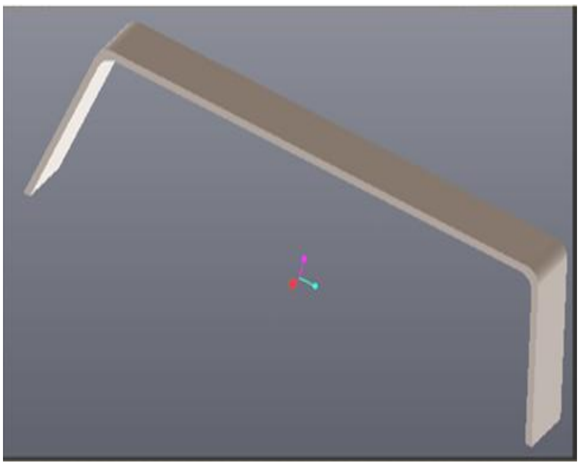
TABLE-3

BIOMATERIAL	t, (mm)	l,(mm)	F,(N)
Stainless Steel Cr-Ni-Mo	2.5	160	640
Ti-6Al-4V	2.5	160	825
Co-Cr-Mo	2.5	160	900

4. RESULTS AND DISCUSSIONS

4.1. Fixation Plate Model - 3D

In this fixation plate model, we are using CATIA V5 Software.



4.2. Meshed with Loading Diagram

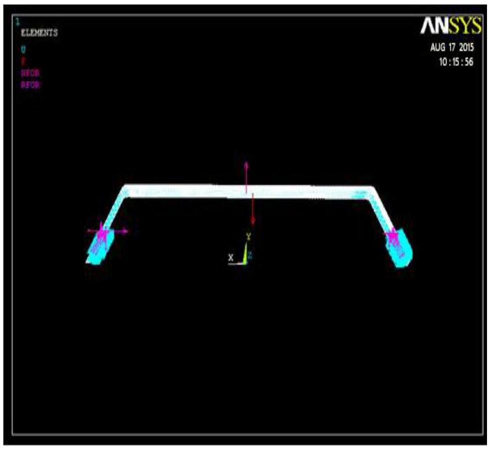


Fig.No.8. Meshed with Loading Diagram

4.6. Analysis Model

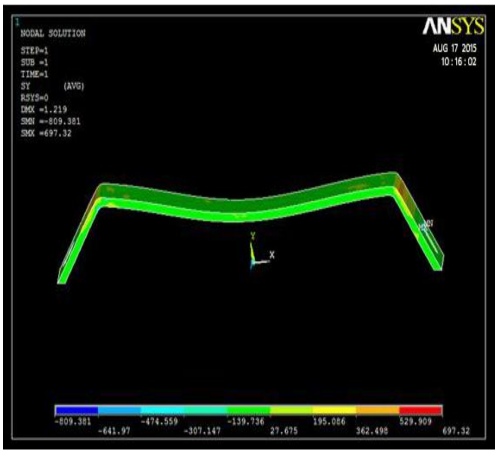


Fig.No.9. Stress distribution in the plate made of stainless steel Cr-Ni-Mo (l=160 mm and t = 2.5 mm)

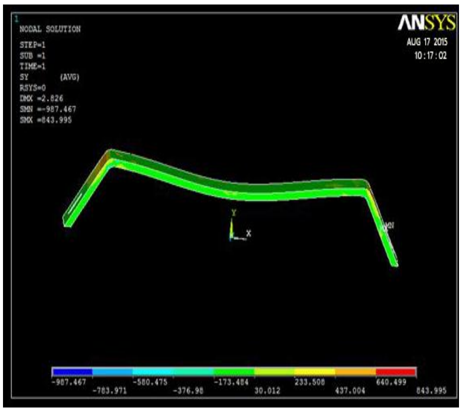


Fig.No.10. Stress distribution in the plate made of stainless steel Ti-6Al-4V (l=160 mm and t = 2.5 mm)

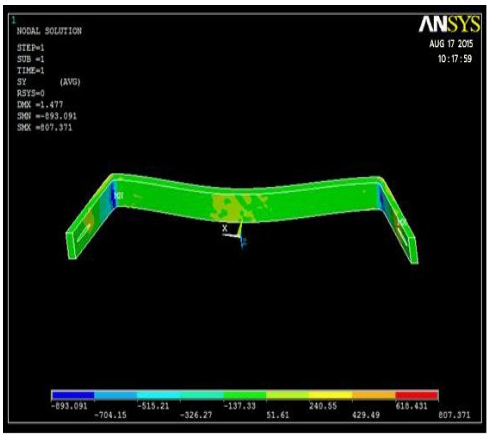


Fig.No.11. Stress distribution in the plate made of stainless steel Co-Cr-Mo
(l=160 mm and t = 2.5 mm)

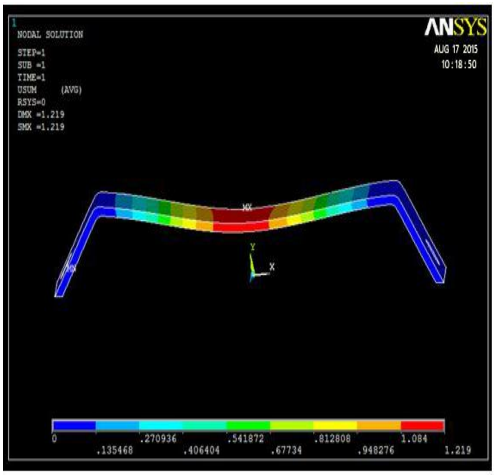


Fig.No.12. Displacement distribution in the plate made of stainless steel Cr-Ni-Mo
(l=160 mm and t = 2.5 mm)

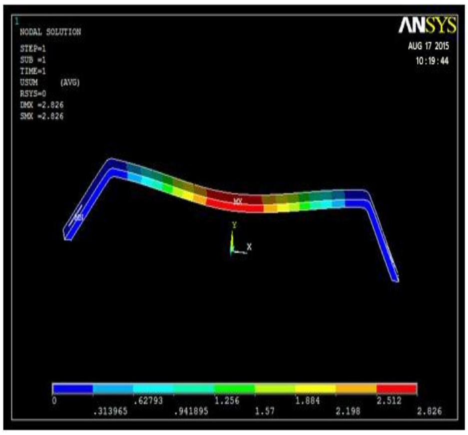


Fig.No.13. Displacement distribution in the plate made of stainless steel Ti-6Al-4V
(l=160 mm and t = 2.5 mm)

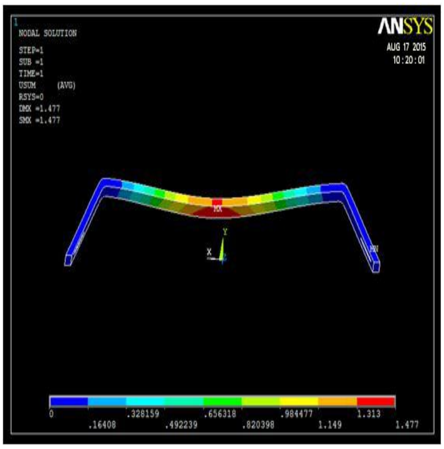


Fig.No.14. Displacement distribution in the plate made of stainless steel Co-Cr-Mo
(l =160 mm and t = 2.5 mm)

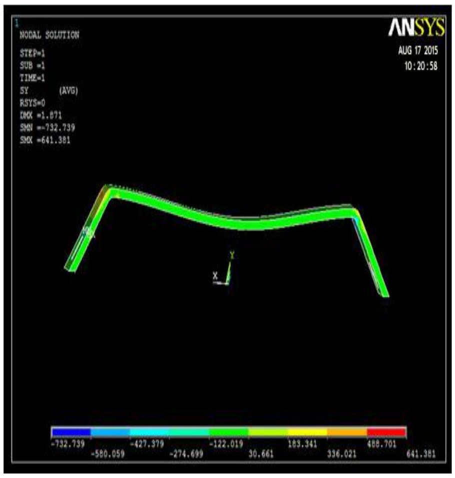


Fig.No.15. Stress distribution in the plate made of stainless steel Cr-Ni-Mo
(l=150 mm and t = 2.5 mm)

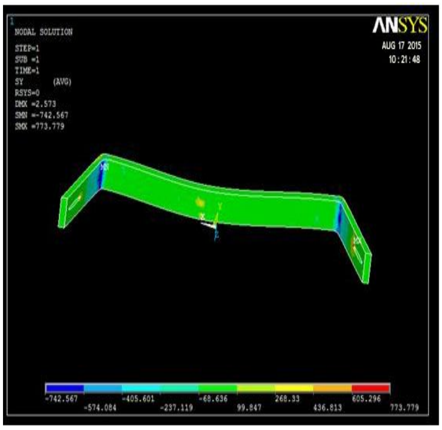


Fig.No.16. Stress distribution in the plate made of stainless steel Ti-6Al-4V
(l=150 mm and t = 2.5 mm)

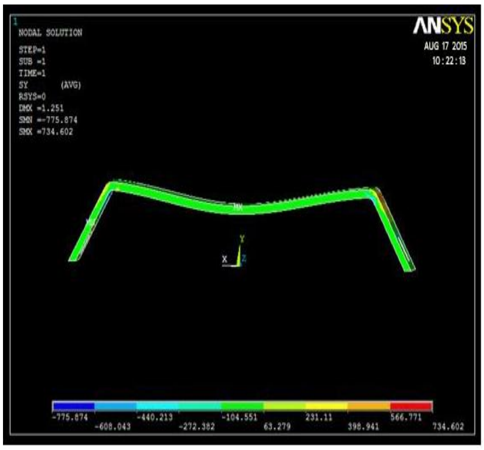


Fig.No.17. Stress distribution in the plate made of stainless steel Co-Cr-Mo (l=150 mm and t = 2.5 mm)

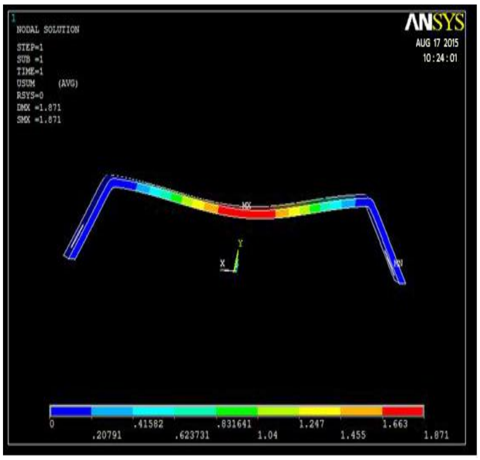


Fig.No18. Displacement distribution in the plate made of stainless steel Cr-Ni-Mo (l=150 mm and t = 2.5 mm)

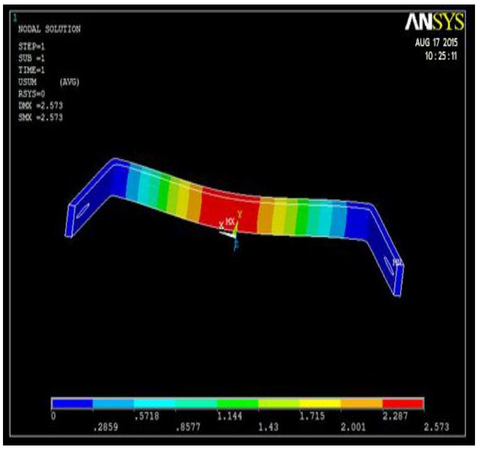


Fig.No.19. Displacement distribution in the plate made of stainless steel Ti-6Al-4V (l=150 mm and t = 2.5 mm)

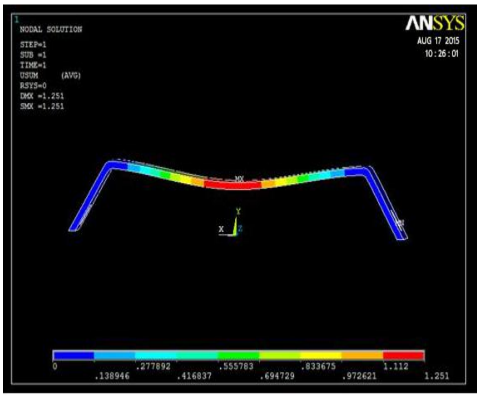


Fig.No.20. Displacement distribution in the plate made of stainless steel Co-Cr-Mo (l =150 mm and t = 2.5 mm)

5.1. Results & Discussion

TABLE – 5

Bio-Mat.,	t, mm	l, mm	F, N	Displ., mm	Stress, Mpa	Strain
Stainless Steel Cr-Ni-Mo	2.5	150	430	1.82	641	1.21
Ti-6Al-4V	2.5	150	555	2.57	773	1.71
Co-Cr-Mo	2.5	150	595	1.25	734	0.834

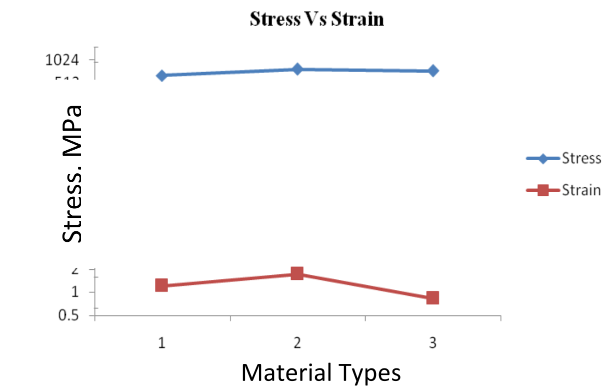


Fig.No.21. Stress Vs Strain for l = 150 mm & t = 2.5 mm

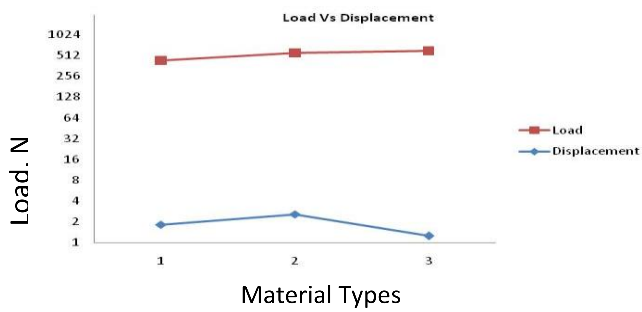


Fig.No.22. Load Vs Displacement (l = 150mm & t = 2.5mm)

TABLE – 6

Bio-Mat.,	t, mm	l, mm	F, N	Displ., mm	Stress, Mpa	Strain
Stainless Steel Cr-Ni-Mo	2.5	160	640	1.21	697	0.75
Ti-6Al-4V	2.5	160	825	2.82	843	1.76
Co-Cr-Mo	2.5	160	900	1.47	807	0.91

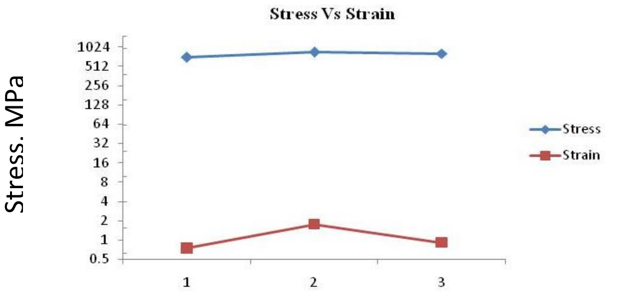


Fig.No.23. Stress Vs Strain for l = 160 mm & t = 2.5 mm

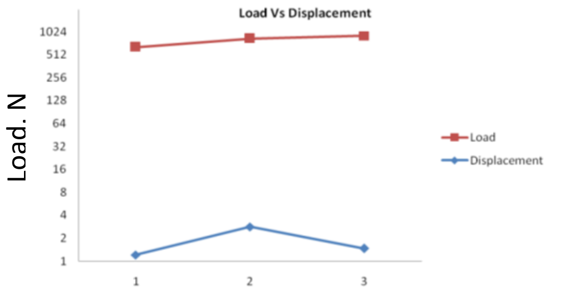


Fig.No.27. Load Vs Displacement (l = 160mm & t = 2.5mm)

5. Conclusion

In order to calculate in displacements, strains and stresses of plates used in treatment of pectus excavatum the numerical analysis was applied. The obtain results are the basis for selection of structure and mechanical properties of the plate.

On the basis of the performed displacement, strain and stresses analysis of the stabilizing plate it can be stated that.

1. Maximum displacement, strain and stresses occurring in the plate cannot exceed from 700Mpa to 850Mpa which are equal to the force affecting the plate in the place where it sticks to the sternum.
2. The minimum displacement was observed for the stainless steel (Cr-Ni-Mo) plate of length l=160 mm and thickness t=2.5 mm (loading force F=640N)
3. Generally, lower displacements values are observed for the plates of the thickness of t=2.5 mm both stainless steel and cobalt alloy.
4. Geometrical features and mechanical properties of the analysed plates enable elastic strains during loading. It determines the basic criterion of clinical application.

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