33

Types and Structures of the Implants

Cüneyt Temiz, Mesut Mete

Applications of spinal instrumentation are used frequently in a growing number in all over the world. Especially, the development of segmental transpedicular screw systems, allow many spine surgery from impossible to possible. Development of metal and / or polymer-composite material, on the one hand provides new approaches for bone fusion problems, on the other hand allows physiological movement of the spine with alone and/or fixed systemsso dynamic-physiological implant comes up. Implant technology, especially the rapid development of computer-aided design and test processes accelerated the changes in spine surgery. Nowadays, to decide right indication and applying the correct techniques are not enough, also itis necessary to know the structure, physical and biological properties of the implants because this new informations changes the surgical indications and methods.

Basically, a spinal implant is a structure that originated from metal, ceramic, polymer, carbon, kevlar, or organic and has some features such as; deterioration in structure and/ or dysfunction, fixing the functional segmental unit (FSU), reducing the movements, reducing the load, providing mechanical support, restrict the movement and supporting the development of bone fusion.Today, implants which reduces the load onthe ISU and edit the sequence with mimicing the natural move mentare called dynamic implants.

Nowadays, to decide right indication and applying the correct techniques are not enough, also itis necessary to know the structure, physical and biological properties of the implants because this new informations changes the surgical indications and methods.

Expected Functions of the Spinal Implants:
1. To allow the physiological movement
2. To restrict the movement completely and prepare the appropriate conditions for fusion
3. Load-bearing
4. To restore the original structure of the spine
5. To provide decompression (direct or indirect)
6. To contribute the pain (5,9,12,13,14)

Implantmaterials: Spinal implantsare usually made from stainlesssteel, titanium (Ti), titanium-aluminum (Al)- and vanadium (Va). Recently, polyetherether ketone (PEEK) which is a polymer material is used especially in intercorporeal cagestructure. However, in recent yearsan increasing numberof carbonalloysor pure carbonstructures are started to be used. This structures are forming to 'foam' cage and in this way it is thought to in crease the quality and speed offusion. Akind of nickel (Ni) - Ti alloy which is called Nitinol has been used in making spinal implant. The most important feature of this material is when heated, remember the earlier shape and rotate the old form. There fore, these alloys are called 'smart metal'. In addition, some ceramic composite materials and natural sea corals are tried to use for this purpose (5).

Spinal implantsare usually made from stainlesssteel, titanium (Ti), titanium-aluminum (Al)- and vanadium (Va). Recently, polyetherether ketone (PEEK) which is a polymer material is used especially in intercorporeal cage-structure.

Implants According to the Compositions and Alloys
1. Polymers (polyether ether ketone, etc.)
2. Ceramics

3. Stainless steel (Vanadium, 302, 316, 316L)
4. Co-Cr alloys
5. Pure titanium and Ti6Al4V
6. Titanium-nickel alloy (Nitinol, a shape memory metal)
7. Tantalum alloy
8. Thermomagnetic Ni-Cu alloy implants
9. Gold, Platinum, Palladium, Osmium alloys
10. Carbon-Titanium-Aluminum Alloys
11. Ceramic materials (1,3,5,6,7,8).

The flexibility of the implant should be as close as possible to the flexibility of bone tissue.

The Most İmportant Features of İdeal Spinal İmplants Are:

1. Mechanical resistance: An ideal implant material should be resistant to the forces which applied on each axis. This property is the highest in steel and followed by Ti-Al-Va alloys. Shape, size and processing methods of the implants effects this feature.

2. Osteointegration: Bone surface of the implantshould have increasing effect on attachment. This property is the highest in titanium alloys. Shapeof the surface structure affects this feature. In recent years, especially in dynamic systems, this feature is trying to be in creased by hydroxyapatite integration to material surface. Especially in osteoporotic vertebra, polymethylmethacrylate (PMMA) is injected by cannulated and open ables crews to in crease this feature.

Corrosion is theabrasionof the metal surfaceas a result of interaction between metal surface and organism.

3. Flexibility: The flexibility of the implant should be as close as possible to the flexibility of bone tissue. In this regard, PEEK material is the most successful material. Material with high flexibility are more resistant against to metal fatigue and breakage.

4. Corrosion resistance: Corrosion is theabrasionof the metal surfaceas a result of interaction between metal surface and organism. This feature is important because of both impairing the material and material's toxic effect due to solubility in body fluids. Processing and coating of the implant surface directly affects this feature Ti alloys are know nas the best resistance materials to corrosion (4).

5. Abrasionresistance in connection points: It is a well-knownfact that abrasion and loosening in connection points, are frequently different in all materials. There fore, all components of the implant should be same. In this regard Tialloys is the most successful material. More over, structure of the connection, directly effect this feature. If contact surface arae is large, resistance to abrasion and loosening is in creased.

Eachmetal can with stand torepetitive loads for a certain time and then failure develops.

6. Galvanic effectressistance: The metallic structures which placed inside organism, begin to actlike the battery which occurred low voltage difference and amparage due to the differences between the electrical resistance and atomic organization this event is known as voltaic-galvanic effectan despeciallyacts a role on the fusion rate by affecting the osteoblasts functions.

7. Fatigue: Eachmetal can with stand torepetitive loads for a certain time and then failure develops. It is called fatigue. This featureis related with amplitude and frequency of repetitive loads and structure of the material. In this regard Ti alloys are known the most successful material (2,3,5,7).

Types of Spinal İmplant:

It will be correct to classify spinal implants into different subgroups.

Implant Types According to Administration Methods :
1. Implants implemented to anterior structures of the spine
2. Implants implemented to posterior structures of the spine
3. Implants implemented simultaneously to both anterior and posterior structures
4. Implants implemented with open surgical approach
5. Implants implemented with 'minimally invasive' techniques
6. Implants implemented with percutaneous techniques
7. Implants implemented over Guidance systems

Implant Types According to the Shape:
1. Screw form implants
2. Cage form implants
3. Plate form implants
4. Disc space cage implants
5. Rods and fittings
6. 'Dynamic'implants with moving structure
7. Irregular-shaped implants
8. Combination form implants

Implant Types According to the Shape:
1. Screw form implants
2. Cage form implants
3. Plate form implants
4. Disc space cage implants

Structural Properties of Implants:
Screws:
Screws used in spinal instrumentation systems can be classified as follows:
1. Self-tapping
2. Self drilling
3. Conical
4. Cylindrical
5. Spongiosisor corticalthreaded(Cross-sectionsurface is cylindrical or trapezoidal)
6. Dynamic
7. Pullerscrew
8. Lag screw
9. Cannulated
10. Elastic
11. Osteoporosis screw
12. Unikortikal-bikortikal
13. Locked
14. Bipediküler
15. Hydroxyapatite-coated (2,5).

Structural Properties of Implants:
Screws:
Screws used in spinal instrumentation systems can be classified as follows:
1. Self-tapping
2. Self drilling
3. Conical
4. Cylindrical

Structure of the Screw:
Screw Head: This part is the connection point between screw and othersystem. Transpedicular screws can be designed as moving (Poliaxial) or fixed (monoaxial) types. Structure of the head may be in U or I form. Monoaxiyaltype is more accuratein trauma or deformity because this type ofscrew head is mechanicaly stronger, on the other handpolyaxial-type has easier implementation. In polyaxial screw, head designing, the possibility of elusion and loosening on the contact surfaces are more. Screw head which applied to the plates are fixed. Screws with large flat surface contact with lower metal and create a fixed system. Where as semi-cylindrical screws creates the basic mechanism of the semi-dynamic systems. Apart from these, there are some that contain locked, cannulated, release pin, elastic rope system or tensioning nut (5).

Monoaxiyaltype is more accuratein trauma or deformity because this type ofscrew head is mechanicaly stronger, on the other handpolyaxial-type has easier implementation.

Screw body: This part include the screw threads which provide the mechanical strength. Many studies reported that breakage is mostly seen at the connection point of head to neck due to high voltage resistance. Screw mechanical resistance is directly proportional to the third power of diamater. There fore use of the thickest screw provides the highest mechanical resistance. Screw body can be conicalor cylindrical. While conical screws are usually used in transpedicular interventions, cylindrical screws are used in cervical plate interventions. It is known that conical screws compress to the surrounding bonetissue while movingin the cancellous bone and it provides high erscratch resistance. Screw threads are found on the body. While threads are short, cylindrical with narrow ranges in cortical screws, they are long, trapezoidal with widerranges in cancellous screws.

Cancellousscrews: Th is screws are mostly self-tapping and provide higher pull out strength.

Cortical screws: Generally, screw diameter andchannel diameter on the bone are same. Often they are not self-tapping.

Cancellousscrews: This screws are mostly self-tapping and provide higher pull out strength. Oftendo not need toturn the channel even this process weakens the bone-metal interface. Self-tapping screws aremore pointedand sharp. In removing orreplacing they havemore risc, but it is easierto place. As forstripping there is no difference between the twoscrew-types.

Adduction (Lag) screws: This screws are used for fixation of odontoid fractures and C1-2 facets. The grooves are located in distalportion. If screws are tightened after the broken line split ends are closure to each other.

Expandable screws: Th is screws are used in osteoporotic vertebrae which can expanded with a special mechanism aft er placing bone.

Cannulated screws: This screws are usually placed on the guidance of a Kirschner wire after wire is placed into the bone and providesmore secureapplication. In recent years, injection of PMMA from inside of this screwsare used for osteoporotic vertebrae.

Expandable screws: This screws are used in osteoporotic vertebrae which can expanded with a special mechanism after placing bone. Revision of screws are difficult (5) (Figure 1).

Elastic screws: This screws are in helical structure and include elasticrope.They are not perforate the cortical bone. Also because of elasticity can be set in desired ratio, this screws can be used as dynamic, semi-dynamic and in rigid forms.

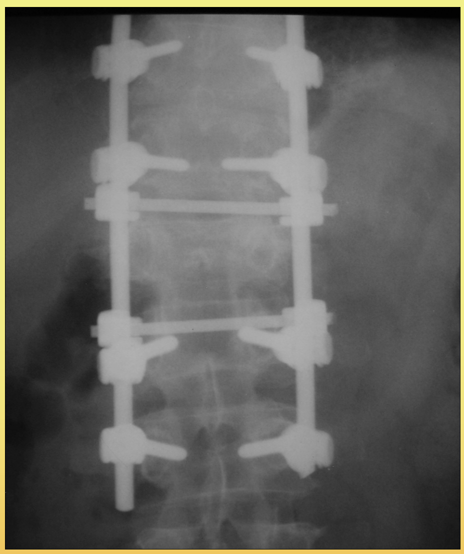
Şekil 1

Pedikül içinde açılabilen vida

Factors affecting the Screw Stripping:

1. Screw diameter: Wide and long screws have high stripping resistance.
2. Associated with cortical bone: Screws related to cortical bone are more resistant to stripping.
3. Screw stripping resistance increases with increasing depth of penetration.
4. Trapezoidal groove shape provide higher stripping resistance.
5. Placement of the screws in diverjant angle, increases the resistance stripping.
6. Placement of the transverse connector increases the resistance stripping (Figure 2).
7. Osteoporosis reduces the stripping resistance.
8. The segment whisch will be stabilized is close to cranial or caudal, possibility of stripping is reduce because lower the torque applied to terminal end.
9. Terminationof the system in joint region reduces the resistance stripping (11,14).

Factors affecting the Screw Stripping:
1. Screw diameter: Wide and long screws have high stripping resistance.
2. Associated with cortical bone: Screws related to cortical bone are more resistant to stripping.



Şekil 2

Transpediküler vida- rodlar ve transvers bağlantılardan oluşan sistem

Cages:
1. Cross-applied thread cages
2. Corpectomy cages
3. Expandable corpectomy cages

Cages:

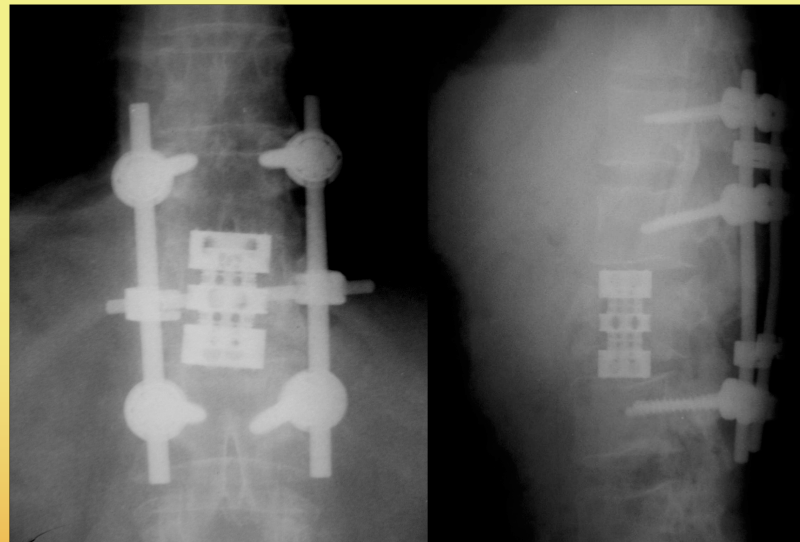
1. Cross-applied thread cages
2. Corpectomy cages
3. Expandable corpectomy cages
4. Disc space cages
5. Expandable the cages with upper and lower end plates
6. Cages with threaded on the upper and lower end
7. Knife cages
8. Screw cages
9. Cage-plate combinations
10. Ceramic, chrome-cobalt foam cages

Basically intercorporea is used to ensure, mechanical support and enhance the development of fusion and fusion surface. These are produced from Ti alloys, PEEK, carbon, ceramic, and composite materials. They can be used to support the disc space as well as in metastatic vertebra tumors to provide faster and stronger reconstruction. They provide high mechanical resistance and fusion rate. They can be in lattice, cylindrical or rectangular shape. Also some types can be expanded in application region (Figure 3). It is known that the appropriate cage that placed at the center of the intercorporeal region provide higher mechanical resistance than bone graft. Recently there are some types that can be expanded and fixed to the upper and lower corpus with combined plates (Figure 4). De-

Basically intercorporea is used to ensure, mechanical support and enhance the development of fusion and fusion surface.

Şekil 3

Açılabilen korpektomi kafesi



Şekil 4

Plaklı- açılabilen korpektomi kafesi

Cages have higher resistance than transpedicular screws and rods against axial compressive loads.

spite high mechanical resistance, placement and revision is difficult (5,6,10).

Cages have higher resistance than transpedicular screws and rods against axial compressive loads. However they tendency to dislocation against torsional forces. For this reason, they often used in combination with anterior intercorporeal plates. New expandable plate cages are designed to eliminate this disadvantage.

Plates:

1. Low and high profile plates
2. Dynamicplates systems
3. Rigid-semi-rigid connection plates
4. Extendable modular plates
5. Plate-rod combinations
6. Cage- plate combinations
7. Laminoplasty plates

Plates are mostly flat metal systems that provide strong stabilization with bone grafts. During stabilization while they behave like taut band in extension, in flexion they provide support. Locking plates are locked after screw placement. They provide stabilization by graft compression. Dynamic plaques are often used in anterior cervical stabilization. They allow loss of height after placing bone graft (5,8) (Figure 5-7).

Recentlymodular plate systems are used with increasing frequency times. Advantage is, it can be extended or shortened by as much as desired but yet there is enough clinical experience. Plates which are used in the laminoplasty are more subtle and in shaped microplate structure. They should be used with bone graft because they can not with stand to mechanical very high powers. In recent years, the rapid development of dynamic implant systems, is mainly reflected to the plates and dynamic plate systems have been used in the transpedicular screw- fixation. Yet there is noadequate clinical experience.
Rods and connection elements (Figure 8:)

Şekil 5

Servikal dinamik plak

Şekil 6

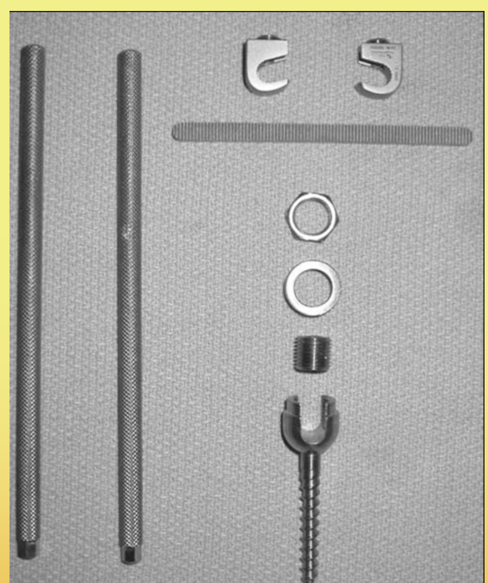
Lomber modüler plak

1. Rigid rods
2. Dynamic rods
3. Cervical-thoracic-lumbar rods
4. ‘Memory’ rods
5. Elastic-semirigid-rigid rods
6. Transition zone rods
7. Percutaneous practical rods
8. I, Y is H-shaped connection elements
9. Transverse connector
10. Clamp, top loading, side loading, prolonged connection elements.

Rods are the main structures that carry the system's load. They provide stability in compression, distraction and rotationaxes. Now a days, Ti-Al-Va of alloyrods are mostly used. Apart from these, there are also varieties of special shaped percutaneous rods. With rod's adjustable sutructure, dynamic, semi-dynamic and fixed rodsare available for use. In recent years, an effort is given to create dynamic systems over the rod. For this reason, spiraling connection, articulated and PEEK polymer rods are began to produce but none has extensive clinical experience (5,6).

Şekil 7

Oksipitoservikal plak-rod sistemi



Şekil 8

Transpediküler U vida, rodlar, transvers bağlantı elemanları

Rod Stripping and Factors Affect the Breaking:

1. Not given proper slope to rod
2. Excessive length system
3. Not tightened the connection elements
4. Hard and reverse angulation consecutively
5. Insufficient number of transverse connector
6. Poor bone fusion.

Transition elements and transverse connectors are provide connection. The traditional knowledge is, editing of the system in square or rectangular shape, in creases the resistance against the rotational forces as well as prevent the screw stripping. The use of the transverse connector is controversial especially in patients with degenerative disease. However, trauma, tumor and configuration of long system is recommended to use.

Dynamic Implants:

1. Screw that capable of flexion and extension.
2. Spiral rods- full dynamic rods
3. Dynamic plates
4. The extensible rods
5. Elastic semi rigid-rigid rods with rope mechanism
6. Elastic semi rigid-rigid screw with rope mechanism
7. Total arthroplasty devices
8. The disc prostheses
9. Prosthetic disc nuclei

In recent years, one ofthe most popular topic is, application of dynamic implants. For this purpose,the artificial disc implants, neck movable screws, body movable elastic screws and multi-platform arthroplasty devices have been developed. However, debate aboutthe implantsis still going on (5,9) (Figure 9,10).

These devices are basically have moving joint surfaces. The surfaces can be metal-metal interface, metal-polymer interface and PEEK interface. These devices' bone attachment surfaces are porous orcoated with materials which react with bone such as hydroxyapatite and thus trying to increase the attacment to bone. However, it is difficult to say that this devices have reached the final development stages.

Irregularly Shaped Implants:

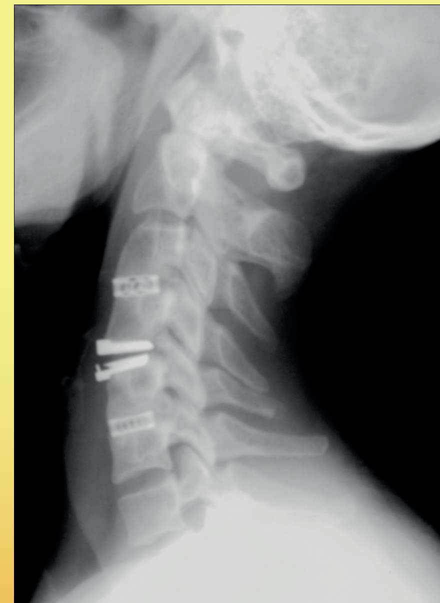
1. Interspinous spacers (Figure 11)
2. Z-Y-U-H-shaped plates
3. Irregular-shaped cages
4. Cables and wires
5. Coupling system
   a-laminar
   b-applied to the Transverse proces
   c-pedicular
   d-hook-screw combinations
6. 'Universal' clamping systems

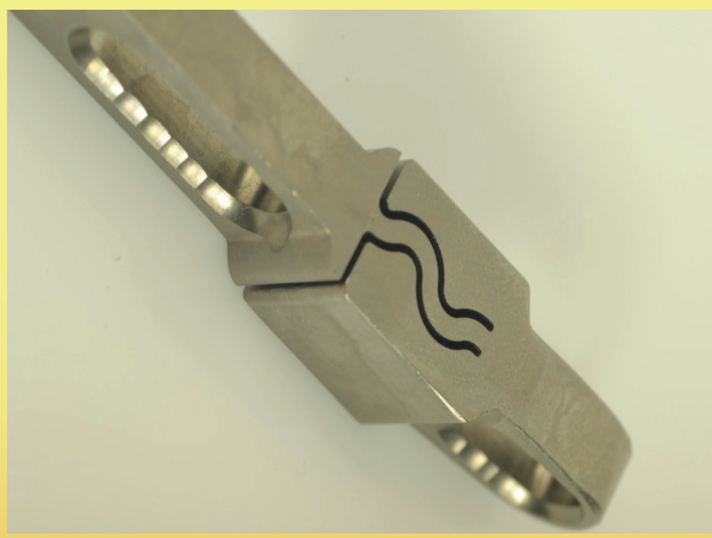
These types of implants are usually designed for specific tasks. Y-P and etc. shaped plates, are often using for occipitocervical stabilization. Irregular cagesare used for anterior stabilization after C2 corpectomy. Interspinous openersare used to increase the height of the foramina in foraminal stenosis and degenerative disc disease. Sublaminar wires that are used for posterior cervical stabilization (Gallie and Brooks technology), are not preferred nowdays, because of high complications rates such as neurodeficitis. In the recent years, Universal clamp system (combination of Ti rod-specific composite flexible strip) is used in deformity surgery. Howeverdevelopment offailure is seenfrequently soit lost its popularity.

In this group, hookis an important structures. It can be placed to sublaminar, subpedicle and transverse process. If the compression-claw configuration is used, they provide strong stabilization (5,8). Use in osteoporotic bone, provide higher resistance stripping

Şekil 9

Servikal yapay disk protezi ve titanyum disk aralığı kafesleri





Şekil 10

Dinamik lomber plak

than screw and also use at the upper thoracic and cervical regions are advantages. However higher neurodeficitis risc is its disadvantage.

Combination Structure of the Implants:

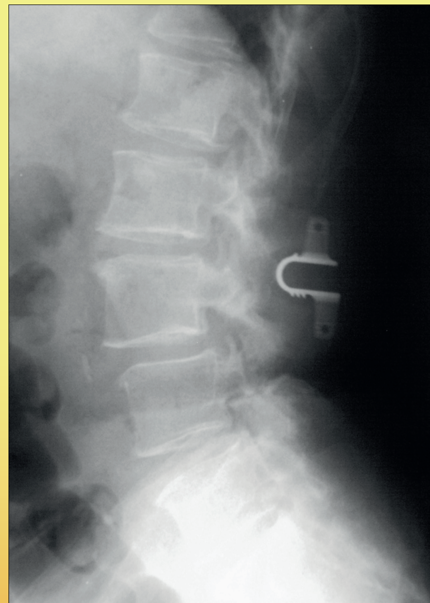
1. Tube-polymer rope combination implants.
2. Titanium alloy screw- rope combination implants.
3. Titanium alloy rod-rope combination implants
4. Polymer, ceramic, carbon and titanium-hydroxyapatite combination disc prosthesis

This group implants are typically developed for dynamic stabilization structures. 'Dynesis' system, is the best-known examplefor this group (Figure 12).

As a classification according to implants origin material:

Şekil 11

İnterspinöz açıcı



Şekil 12

Tüp- polimer bileşiminde dinamik implant

According to the Compositions and Alloys Implants can be Summarized as:

1. Polymers (polyether ether ketone, etc.)
2. Ceramics
3. Stainless steel (Vanadium, 302, 316, 316L)
4. Co-Cr alloys
5. Pure titanium and Ti6Al4V
6. titanium-nickel alloy (Nitinol, a shape memory metal)
7. Tantalum alloy
8. Ni-Cu alloy implants thermomagnetic
9. Gold, Platinum, Palladium, Osmium alloys
10. Carbon-titanium-aluminum alloys (2,3,5,10).

As a result, all implants used in spinal stabilization has different characteristics and indications. To be dominated, these features will increase the success of spinal implant applications.

References

1. Barrere F, Snel EMM, Blitterswijk CA, et al: Nano- scale study of the nucleation and growth of calcium phosphate coating on titanium implants. Biomaterials 25: 2901- 2910, 2004
2. Bennet GJ: Material and material testing, in Benzel EC (ed): Spinal Instrumentation, AANS, 2002
3. Boyer R. Titanium alloys in Welsch G, Collings E (eds): Materials Properties Handbook: ASM International, Metals Park. 1994, OH
4. Cunningham BW, Hallab NJ, Hu N, McAfee PC. Epidural application of spinal instrumentation particulate wear debris: a comprehensive evaluation of neurotoxicity using an in vivo animal model. J Neurosurg Spine. 2013
5. Çağlı MS: Spinal enstrüman elemanları, in Naderi S (ed): Spinal Enstrümantasyon, TNDSPSCG, 2004
6. Dee CK, Bizios r. Mini- review: Pretective biomaterials and bone tissue engineering. Biotechnology and Bioengineering 50: 438- 442, 1996
7. Freese hl, Volas MG, Wood Jr, et al. Titanium and its alloys in biomedical engineering: Science and technology encyclopedia of materials: Science and Technology, Elsevier Science Ltd, 2001
8. Huhn SL, Wolf AL, Ecklund J: Posterior spinal osteosynthesis for cervical fracture/dislocation using a flexible multistrand cable system:Technical note. Neurosurgery 29: 943-46, 1991
9. Jahng TA, Kim YE, Moon KY. Comparison of the biomechanical effect of pedicle-based dynamic stabilization: a study using finite element analysis. Spine J. 13(1):85-94, 2013
10. Kostuik JP, Smith TJ: Pitfalls of biomechanical testing. Spine 16: 1233- 1235, 1991
11. Ruland CM, McAfee PC, Warden KE, et al: Triangulation of pedicular instrumentation. A biomechanical analysis. Spine 16: 270- 276, 1991
12. Salmingo RA, Tadano S, Fujisaki K, Abe Y, Ito M. Relationship of forces acting on implant rods and degree of scoliosis correction. 28 (2): 122- 128, 2013
13. Sell P, Collins M, Dove J: Pedicle screws:Axial pull-out strenght in the lumbar spine. Spine 13: 1075- 1076, 1988
14. Vangsness CT Jr, Carter DR, Frankel VH: In vitro evaluation of the loosening characteristics of self-tapped and non-self-tapped cortical bone screws. Clin. Orthop. 279-286, 1981