Metallic implants in orthopaedics

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Metallic implants are the main materials in the orthopaedic application. Criteria for the selection of appropriate metals are different in each application. Some important characteristics have, therefore, to be considered eg. mechanical performance, material biocompatibility and functional compatibility of implants. The article gives an overview of these characteristics of some important metal currently used in orthopaedics.

Key words : *Metallic implant, Orthopaedics.*

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Objectives

1. To know the roles, new trends, and update management of the orthopaedic implant fixations.
2. To understand the basis of the properties of the metals and their applications in the orthopaedics practice.

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วัสดุโลหะเป็นสิ่งที่จำเป็นต่อการผ่าตัดทางออร์โธปิดิกส์มากที่สุด ชนิดของโลหะที่ใช้มีความเหมาะสมแตกต่างกัน ซึ่งขึ้นอยู่กับการใช้งาน คุณสมบัติของโลหะที่ต้องคำนึงถึงในการใช้งาน ได้แก่ ความแข็งแรง ความเข้ากันได้กับเนื้อเยื่อ และความเข้ากันได้กับการใช้งาน เป็นต้น บทความนี้เป็นการรวบรวมคุณสมบัติและการใช้งานของโลหะทางออร์โธปิดิกส์ที่ใช้กันอยู่ ตลอดจนแนวโน้มและวิวัฒนาการในอนาคต

คำจำกัดความ : *โลหะ, ออร์โธปิดิกส์*

The body is a harsh chemical environment for foreign materials. An implanted material can have its properties altered by body fluids. Ion concentrations and pH changes in body fluids can accelerate degradation mechanism, such as corrosion or leaching. The body's response to an implant ranges from benign to a chronic inflammatory reaction. The degree of biological response are largely dependent upon the biochemical nature of the implanted material. For optimal performance, implanted materials should have suitable: mechanical strength, biocompatibility, and structural biostability in physiologic environments.

Minimizing the local and systems response to an implanted material through improved biocompatibility is the only engineering concern for reconstructive implant surgery. A prosthetic implant needs be capable to tolerate adequate stress-transfer that may cause pressure necrosis and/or resorption at the bone implant interface. Necrotic and resorbed bone may loosen the implant or re-locate it, which shorten the implant life span. Finally, material properties that are capable of sustaining the cyclic body force to which the implant will be subjected are essential. For example, if the material properties are not adequate for load sharing, the implant may fail due to fracture. However, if the material properties are such that stress shielding of the bone occurs, then bone resorption and implant loosening are sure to occur.

Metallic implant in general orthopaedic surgery

All the original synthetic material used for the fabrication of orthopaedic implants is largely made from metallic alloys, based upon the primary elements of iron, cobalt or titanium. Metals of single-element compositions, such as Titanium (Ti) or Zirconium (Zr) found their applications; however, considerations of the strength of orthopaedic implants are crucial for most non-alloy structures.

The biomaterial components of devices have physical and mechanical properties and they are directly depend on the construction material, i.e., the internal metallurgical conditions of the material, shape, form and surface of the final device. After passivation to produce an oxide surface, the alloys used are more ductile and conductors of heat and electricity. The conductivity characteristics of metal are important regarding biodegradating phenomena-,i.e., combinations of biomaterials for device construction and clinical application near the skin surface.

Design criteria are dependent on basic elastic properties of synthetic substances for tissue replacement. The elastic criteria for properly matching is best expressed by the modulus of elasticity. The property is the shape of the mechanical stress-versus-strain relationship for each biomaterial or tissue . The modulus is a basic measurement of a substance's inherent elastic flexibility. Some confusion arises related to relative interpretation of moduli. Generally, this is because most clinicians consider elasticity as a measure of elastic strain or deformation. High-magnitude elastic strains are directly correlated with lower-elastic moduli. Conversely higher-elastic moduli materials, have low-magnitude elastic strain characteristics.

One reason for the extensive use of metallic alloys in orthopaedic implants is related to the availability of relatively strong and inert materials over recent history. Prior to 1925, most available metallic systems were evaluated, and the selection of the electro-chemically noble elements was most common. Alloys of iron and cobalt followed with the introduction of titanium in 1951, and since that time, most alloy systems were based upon iron, cobalt, or titanium. In contrast to the noble metals, these alloys are used in an oxidized or passivated surface condition, which provides stability as related to corrosion. This has resulted in national (ASTMF4) and international (ISO)[1,2] materials standards for most classes, metallurgical conditions, and surface finishes. The specifications provide detailed requirements for nominal chemical analyses, mechanical properties, and surface conditions. Limits with respect to minimally acceptable property values are provided in the standards. Because of the availability of specific property information and clinical experience, design criteria evolved to optimize device longevities. New applications for devices are often simple changes of shape or surface conditions to better control the biomaterial tissue interface.

Orthopaedic devices are most often fabricated from the iron-based surgical stainless steel because of the inherent strength and ductility. However, the stainless steel should not be used for porous implants owing to its susceptibility to crevice corrosion. The most commonly used metallic systems and selected properties are summarized in Table 1.

The various metallic biomaterials exhibit significantly different magnitude moduli. Strength and surface properties. It is useful to think of these property characteristics as a ratio to the similar measurements for compact bone comparative data and ratios are provided in Table 2.

Note that all alloys have moduli of elasticity that are at least five times higher than compact bone. Also strains (elongations) to fracture greatly exceed the limits of bone. This therefore, directly influences design criteria for orthopaedic implants.

The alloys of iron and cobalt have chromium oxide-based surface when prepared in a passivated (oxidized) surface condition. The oxide is like a ceramic coating, although it is a very thin film and not visible under normal light. This thin surface layer provides improved resistance to biodegradation. It is most

Table 1. Metallic biomaterials commonly used for the construction of orthopedic surgical implants. (Freidman et al)[3]

Material	Nominal Composition (w/o)	Tensile Strength Mpa (psi)	Modulus of Elasticity Gap (psi X 10)	Surface Condition
Cobalt alloys				
Cast	Co-27Cr-1Mo	655(95)	235(34)	Cr_xOy
Wrought	Co-26Cr-			
	(Ni, Mo, W, Fe)	1172(170)	235(34)	Cr_xOy
Surgical stainless	Fe-18Cr-12Ni	480-1000		
Steel (316L)		(70-145)	193(28)	Cr_xOy
Titanium alloy	Ti-6A1-4V	860-896		
		(125-130)	177(17)	Ti_xOy

Table 2. Metallic biomaterial and tissue properties. (Freidman et al)[3]

Material Fracture or TissueElongation	Modulus of Elasticity GPs(psi x 10^0)	Tensile Strength Mpa (psi)	Ratio (Material - Bone) Elongation to fracture (%) Modulus Strength			
Compact bone	21 (3)	138 (20)	1	1	1	1
Cobalt alloys	235 (34)	655 -1172 (95 -170)	> 8	11	5 -9	>8
Stainless steels	193 (28)	480 -1000 (70 -145)	>30	9+	4 -7	>30
Titanium alloy	117 (17)	860 -896 (125 -130)	>12	5+	6 -7	>12
Titanium	96 (14)	240 -550 (25 -70)	>15	5+	1 -4	>15

critical for the iron alloy systems, which are subject to crevice or pitting corrosion if the oxide surface layer is broken down in vivo.[4]

Titanium alloy might have a titanium oxide surface that will form very rapidly in room temperature air or titanium nitride surface that needs special preparation. This oxide or nitride passivation reaction make titanium systems resistant to surface breakdown when used in a porous condition. The titanium-based system has a lower modulus of elasticity compared to the iron alloys. This basic material property is less by a factor of about two times and must be taken into account when designing, load-bearing device. Design changes should include size or shape alteration to accommodate elastic property difference.[6]

Electrochemical properties

Another consideration for physical condition is in the selection and use of implant devices; this is the basic electrochemistry and property relationship of biodegradation phenomena. As for metallic systems, the phenomena can be described by corrosion mechanisms.

One of the more useful characterizations of metallic materials is galvanic series, which provides electrochemical comparison in saline solutions. The series also permits theoretical predictions of galvanic coupling, or the relative corrosion behavior of two conductors that are electrically coupled within the host and therefore the same electrolyte environment. Galvanic coupling, with an associated enhancement of in vivo corrosion, depends on a number of environmental factors. The magnitude and increase (or decreased) rate of corrosion depends on the environment (eg., fluid, soft tissue, or bone) and local transport phenomena, surface interaction such as wear (fretting or local oxide removal): relative surface area ratios of the components, galvanic potential difference, metallurgical condition of the alloys, localized oxygen potential difference, and localized oxygen and ionic species concentrations and gradients. Increase of corrosion in vivo is to be avoided because of biocompatibility considerations that emphasize the importance of this type of biomaterial and host information. A general rule is that surgical stainless steel should not be coupled with other alloys or carbon. In contrast, titanium, titanium alloy, and cobalt alloys have relatively

Table 3. Corrosion data from potentiostatic polarization. (Skinner)[7]

Material	Equilibrium corrosion potenital and rate from potentiostatic polarization	
	E_c(mV)	ic(a/cm^2)
Ti		
Solid	-14	0.013
Porous	-10	0.044
Ti-6A1-4V		
Solid	-50	0.003
Porous	-75	0.014
Co-Cr-Mo		
Solid	-10	0.011
Porous	-35	0.028
Fe-Cr-Ni (316L SS)		
Solid	-49	0.008

similar electrochemical potentials. Studies of the coupling of titanium in vivo and cobalt- based alloys have not demonstrated significant increase in the corrosion of either component.

Potentiostatic and dynamic polarization data provided detailed comparisons of solid and porous alloy implant systems. (Table 3)

Biomechanical features

Correlations of biomaterial properties and performance in vivo are major activities of researches and clinical communities. As a broad evaluation, material of the highest-possible, strength, ductility, biodegradation resistance were selected. However, the selections have also included the important consideration of availability fabricability and cost.

Wear

Alloys demonstrate varying degrees of wear resistance. Most are susceptible to breakdown (fretting) if the stresses localized contact are excessive. However, iron alloy has more wear resistant than titanium alloy. When titanium alloys, are exposed to metallic contact and relative movement, undergo surface galling (roughening) and breakdown. The phenomenon is characteristic for reactive-group metals and alloys and is related to the oxidation and environmental behavior of the metals involved. In vivo breakdown of titanium is normally seen as a black zone within the tissue; cobalt alloys show green-blue, and iron alloys are noted as a dark brown coloration in adjacent zones.[8]

Biocompatibility

The principal alloying elements in Ti-6A1-4V were evaluated with respect to in vivo biocompatibility. Aluminium and vanadium ions in vivo were associated with adverse tissue response. Thus, some manufacturers were initiated the introduction of alloys with other elements as principal constituents. This is a most interesting situation in that corrosion potentials, currents, and device evaluation do not support signification clinical or tissue problems with Ti-A1-V alloy. Comparisons of structure, property, and application relationships should provide greater insights into the long-term tissue responses to the alloy series.[9]

Manufacturing quality control and assurance is an aspect of the longevity of devices. longevities. Industries fabricate implant devices with precision and accuracy standards that exceed most other industrial application requirements. Implant devices should have a "zero defect" specification and this is a desirable recommendation. National (ASTMF4) and international (ISO) consensus standards and recommended practices are available for most metallic materials utilized for orthopaedic devices. The ASTM F4 standards volume provides an excellent reference for biomaterials properties and standardized manufacturing practices. The publications also include test methods, practices for biocompatibility testing.

Biological aspects

Biodegradation from environmental exposure results in substances, such as particulate and ionic forms in the in vivo milieu. The questions related to metallic ion release and tissue responses can be namely categorized into: areas of local tissue reaction (toxicity), allergy or hypersensitivity and carcinogenicity. A well-known document reports that tissue has limited tolerance related to metallic product concentrations. Fortunately, the amounts of productions transferred from devices to local and systemic tissues have, for the most port, been within the tissue's limits of-tolerance. This is demonstrated by a general evaluation of a numbers of metallic devices used over the past 50 years and thir associated longevity profiles. Recent literature shows that hypersensitivity to metallic components should be more seriously considered. A small, but significant, portion of the population will react to nickel-or cobalt-based alloys. Since surgical stainless steel and cobalt alloys contain nickel; applications containing these alloys in allergic patients should be carefully evaluated. Some reports even illustrate accumulations of metal and metallic debris within organs at the implanted location or corrosion sites. A number of reports, although limited in number, describe area-specific sarcomas at the implanted locations. The entire area has been of concern to every party involved and reports of any available clinically relevant data are strongly recommended.

Metallic implants for fracture fixation

The implant materials for internal fixation must, be able to fulfil their task of providing temporary fixation of the fracture, to allow functional treatment. Herein, a good fatigue resistance is required. They must be ductile enough to maintain strength, after being adapted to the bone surface. The stress relaxation given by the implanted should remain minimal, to maintain compression. The material should not degrade in an uncontrolled way. Last, the implant material must be available continuously, at defined quality, while allowing appropriate qualities for machining and contouring at surgery.

In the treatment of fractures, metals are the mainstays of materials because of their strength and ductility. They should be, shaped to fit the bone surface, and their biocompatiblity should be generally acceptable. Other than the implant material selection, the design of implant for fracture fixation are also important to fit the purpose of the fixation. They may be designed in plates, nails, screws, pins, wires or hooks.

Steel

Steel is composed mainly of iron, and some small ratios of chromium, and nickel. It corresponds to international standards (ISO TC150 5832/1) which define its two grades of carbon content and four grades of cold work, from annealed to extra hard. Presentday's steel is all-round material with a good combination of strength, ductility, and prices. Its corrosion resistance and compatibility are fair.

Titanium

Titanium and titanium alloys are finding increased use as implant materials due to their elastic modulus and good biocompatibility. Cold worked (30%), commercially pure titanium is used for bone plates with a fatigue strength comparable to that of medium cold worked.

Commericially pure titanium (c.p. Ti) consists of titanium and oxygen. Titanium is extremely insoluble; subsequently, it is inert and compatible. According to Steinemann(1988) the body is saturated with titanium and, therefore, no additional soluble titanium can become active. Cases of sensitization as reported for nickel, to our knowledge, have not been observed, when only c.p. Titanium was used as implant material. It is still available today in grades that which combine good strength with ductility (ISO TC150 5832/2). Its price, however, is higher than that of steel. Ti6A14V, an alloy of titanium, aluminum and vanadium, offers excellent strength and fair ductility (ISO TC150 5832/3). The corrosion characteristics of Ti6A14V are excellent. For a alloy, the risk of sensitization to one of the components increases with their number. As an element Vanadium is known to be about 10 times more toxic than nickel. Other titanium alloys aim at strength (e.g., TiAlFe or TiAlNb) or at a combination of strength and ductility (Ti-beta alloys).

Other Alloys

Chrome-cobalt alloys do no longer find wide applications in internal fixation. Tantalum and niobium are proposed as implant materials but have, to date, not found widespread application, due to their lack of important advantages.[5]

Metallic implants in orthopaedic joint replacement

The most commonly biomaterials used for orthopaedic joint replacements are metals and their alloys, articulated with ultra high molecular weight polyethylene. Although stainless were used in earlier prosthetic components,cobalt chromium-molybdenum (Co-Cr-Mo) alloy and titanium-aluminum-vanadium (Ti-6A1-4V) alloy are the materials of choice for implantation.

✧ Iron-based alloys

There are four major classes of iron-based alloys or stainless steels grouped according to their microstructure. The austenitic or Group III stainless steels (316 and 316LVM) are used for orthopaedic implants. The inclusion of molybdenum to these alloys hardens the passive layer and increase pitting corrosion resistance. Lowering the carbon content also increases corrosion resistance. Despite their modifications of composition, implanted stainless steels are susceptible to corrosion inside the body. Therefore, they are most appropriate for temporary devices such as bone plates, bone screws, nip nails, and intra-medullary nails.

✧ Titanium and titanium-based alloys

Commercially pure titanium and titanium-based alloys are low-density metals, having chemical properties suitable for implant applications. Titanium has a high corrosion resistance, attributed to its oxide surface layer, which also creates a chemically non-reactive surface to the surrounding tissues. The modulus of elasticity, approximately 110 GPa, is half the value for cobalt-based alloys; but it is still at least five times greater than the elasticity of bone. The higher the impurity content of the metal, the higher the strength and brittleness. Due to their low density, titanium and titanium-based alloys have superior specific strength (strength per density) over all other metals. However, titanium has poor wearing resistance, making it unsuitable for articulating surface of implant applications.[4]

✧ Cobalt-based alloys

The chemical composition requirements for cobalt-based alloys have been studied in details. Molybdenum is added to the alloys to produce finer grains, and consequently a higher strength. Cobalt-based alloys have a mechanical property that is suitable for load bearing implant applications. High fatigue and ultimate tensile strength which makes them appropriate for applications requiring long service life without fracture characterize these alloys. The high wear resistance of these alloys also makes them desirable for load bearing and articulating surface applications.

✧ Implant design and biologic fixation

Several types of implant fixation methods and surface texture designs have been investigated to obtain better surgical fitness and stress distribution at the implant-bone interface. These methods include direct bone apposition to the implant surface, PMMA bone cement, bone growth into porous surfaced implants, and chemical bonding between bone and surface-active ceramic implant coatings.

✧ Direct Bone Apposition

Optimal osseointegration at the bone-implant interface is affected by material properties and design of the implant. Implant design encompasses both the surface texture and geometry of the implant. The mechanical properties of the implant-bone interface have been investigated with various surface preparations : smooth finish, roughened or grit-blasted finished, and grooved surfaces. Histologically, implants with smooth finishes have interfaces characterized by areas of direct bone apposition. Several studies determined that surface texture is a signification factor in obtaining adequate implant fixation with direct bone apposition methods.

✧ Porous Ingrowth Attachment

It is generally accepted that an implant stabilized when there is a tissue growth into its porous-surfaced and bioinert structure, when there is a direct apposition of the bone at the implant interface, or there is minimal or no movement at the implant site, or when the porous structure has appropriate pore size and morphology. The effectiveness of porous coatings as a means of biologic fixation becomes apparent when considering interfacial mechaniocal properties. The interface attachment strength of porous implants relying on bone ingrowth for fixation are at least are order of magnitude higher than that of non-porous implants relying on direct bone apposition for fixation. Several types of porous structures have been evaluated: irregular, fiber mesh, and bead; however, bead porous coatings were extensively studied more than the rest.[7]

To maintain optimal bone growth into a porous structure, the size of the pores have to be large enough to accommodate bone tissue development. A number of investigators studied the degrees and rates of bone ingrowth associated with pores of different sizes. Although a pore size of 100 μm allows bone ingrowth, a pore size larger than 150 μm is found necessary for bone formation. Others reported that a pore size ranged between 50 - 400 μm provided maximum attachment strength in the shortest time. So far, there has been no report of advantages or disadvantages in bone ingrowth for the two most common alloys, Ti-6A1-4V and Co-Cr-Mo. However, histologically it was observed that osteon formation did not appear to be a prerequisite to attain maximum attachment strength.[8]

Besides a minimal pore size, an effective porous coating must also have appropriate pore morphology. The available porous layer for bone growth has to be large enough to accommodate adequate size of bone tissue that enables fixation, without compromising the mechanical properties necessary for effective biologic fixation for a strongly bonded porous layer. The volume fraction porosity is related to the interconnection pore size, particle interconnectivity, and particle size of the interconnection pore size, particle interconnectivity, and particle size of the porous coating. Particle interconnectivity is important for ensuring adequate strength with the coating and between the coating and substrate. However, too much particle inter-connectivity can decrease the interconnection pore size as well as it can restrict the amount and type of ingrown tissue. It is accepted that a two-layer porous surface creates an interconnected and open porosity that is effective in creating a three-dimensional mechanical interlock of the ingrown bone.

✧ Optimizing Biologic Attachment Methods

Optimal attachment at the bone-implant interface is affected by the material properties and design of the implant. Other conditions that affect osseointegration instrumentation design, surgical technique, initial implant stability, and direct contact with the surrounding bone. Initial implant stability and apposition with bone are not always achievable but are vital for implant longevity. Persistent micromotion at the bone-implant interface has been an established cause of bone resorption and necrosis. Necrosis and destructive bone remodeling often result in fibrous tissue infiltration at the interface and may cause implant loosening. Also, any initial gap between the implant and the surrounding bone may adversely alter the amount and rate at which osseointegration occurs.

✧ Motion at Bone-Implant Interface

Motion of an implant within a surgical site, has a primary influence on biologic fixation and implant longevity. The stability of the initial implant is essential for early tissue infiltration, within the porous structure, to differentiate into bone by either direct bone formation or appositional bone growth. Excessive early movement at the bone-implant interface, inhibits bone formation within the pores. The majority of the researches concerning motion at the interface have involved porous implants; however, the findings are applicable for press-fit implant systems.

✧ Surgical Fit

The technical difficulties in cutting bone precisely to provide an exact shape for the implant often result in a poor surgical fitting. Difficulties in achieving initial implant-bone interface apposition are dependent on the instrumental design and surgical technique. Many researchers have investigated the effect of interface gap spaces on the histological response to implants. Significantly reduced mechanical strength and bone ingrowth and/or apposition is generally reported with gaps' width larger than 1 mm.[4]

Conclusion

The mechanical and chemical properties of metals, such as titanium, titanium-based alloys and cobalt-based alloys, suite them for implant applications. However, several factors that affect biological responses to the implanted materials. The predominating tissue found at the implant interface is affected by implant stability, material biocompatibility, and implant design and placement in surgical site. Improvements in implant design, material selection and surface preparation may improve longevity and fixation for all implants in the future.

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กิจกรรมการศึกษาต่อเนื่องสำหรับแพทย์

ท่านสามารถได้รับการรับรองอย่างเป็นทางการสำหรับกิจกรรมการศึกษาต่อเนื่องสำหรับแพทย์ กลุ่มที่ 3 ประเภทที่ 23 (ศึกษาด้วยตนเอง) โดยศูนย์การศึกษาต่อเนื่องของแพทย์ จุฬาลงกรณ์มหาวิทยาลัย ตามเกณฑ์ของศูนย์การศึกษาต่อเนื่องของแพทย์แห่งแพทยสภา (ศนพ.) จากการอ่านบทความเรื่อง **"การใช้วัสดุโลหะในการผ่าตัดทางออร์โธปิดิกส์"** โดยตอบคำถามข้างล่างนี้ พร้อมกับส่งคำตอบที่ท่านคิดว่าถูกต้องโดยใช้แบบฟอร์มคำตอบท้ายคำถาม แล้วใส่ซองพร้อมซองเปล่า (ไม่ต้องติดแสตมป์) จ่าหน้าซองถึงตัวท่าน ส่งถึง

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จุฬาลงกรณ์เวชสารขอสงวนสิทธิ์ที่จะส่งเฉลยคำตอบพร้อมหนังสือรับรองกิจกรรมการศึกษาต่อเนื่องอย่างเป็นทางการ ดังกล่าวแล้วข้างต้นสำหรับท่านที่เป็นสมาชิกจุฬาลงกรณ์เวชสารเท่านั้น สำหรับท่านที่ยังไม่เป็นสมาชิกแต่ถ้าท่านสมัครเข้าเป็นสมาชิกจุฬาลงกรณ์เวชสารสำหรับวารสารปี 2545 (เพียง 200 บาทต่อปี) ทางจุฬาลงกรณ์เวชสารยินดีดำเนินการส่งเฉลยคำตอบจากการอ่านบทความให้ตั้งแต่ฉบับเดือนมกราคม 2545 จนถึงฉบับเดือนธันวาคม 2545 โดยสามารถส่งคำตอบได้ไม่เกินเดือนมีนาคม 2546 และจะส่งหนังสือรับรองชนิดสรุปเป็นรายปีว่าท่านสมาชิกได้เข้าร่วมกิจกรรมการศึกษาต่อเนื่องที่จัดโดยจุฬาลงกรณ์เวชสาร จำนวนกี่เครดิตในปีที่ผ่านมา โดยจะส่งให้ในเดือนเมษายน 2546

คำถาม - คำตอบ

1. Titanium's one of the most biocompatible implant materials because
    a. nothing in the biologic environment resets with titanium
    b. physiologic conditions inhibit titanium reactions
    c. proteins coat the titanium and isolate it from the body
    d. titanium spontaneously forms a thin oxide film coating
    e. titanium alloys are less reactive than pure metal

✂..

คำตอบ สำหรับบทความเรื่อง **"การใช้วัสดุโลหะในการผ่าตัดทางออร์โธปิดิกส์"**
จุฬาลงกรณ์เวชสาร ปีที่ 46 ฉบับที่ 2 เดือนกุมภาพันธ์ พ.ศ. 2545
รหัสสื่อการศึกษาต่อเนื่อง 3-15-201-2000/0202-(1003)

ชื่อ - นามสกุลผู้ขอ CME credit .... **เลขที่ใบประกอบวิชาชีพเวชกรรม**..............................
ที่อยู่..

1. (a) (b) (c) (d) (e)   4. (a) (b) (c) (d) (e)
2. (a) (b) (c) (d) (e)   5. (a) (b) (c) (d) (e)
3. (a) (b) (c) (d) (e)

2. Which of the following metals have the elastic modulus close to bone

a. Titanium
b. Stainless steel
c. Cobalt chrome alloy
d. Zirconium
e. Molybdenum

3. Which of the following properties that is not important for Orthopaedic implant ?

a. Biocompatibity
b. Mechanical performonce
c. Functional compatibility
d. Heat stable
e. All of above

4. What of the following metals that produce the cell toxicity

a. Cobalt
b. Titanium
c. Nickel
d. Molybdenum
e. Chromium

5. Which of the following properties of titanium is suitable for fracture fixation

a. High elastic modulus
b. Less stress shielding effect and cortical osteoporosis
c. High stiffness
d. Less wear resistance
e. Ferromagnetic

ท่านที่ประสงค์จะได้รับเครดิตการศึกษาต่อเนื่อง (CME credit)
กรุณาส่งคำตอบพร้อมรายละเอียดของท่านตามแบบฟอร์มด้านหน้า

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