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ECONOMIC VIABILITY OF β TITANIUM ALLOYS FOR APPLICATION IN ORTHOPEDIC IMPLANTS

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Abstract. *The choice between materials used in orthopedic implants is based on technical aspects as well as economic factors. Some materials used for this propose present some adverse aspects, such as different properties from those presented by human bone and can present disorders in the implanted biological system, as in case of the Ti-6Al-4V alloy. β-type titanium alloys are composed of non-toxic and biocompatible elements, such as niobium and tantalum, and have properties suitable for use as a permanent implant in the human body, such as corrosion resistance and biocompatibility. Even with adequate properties to be used as materials for orthopedic implants, in a general way, titanium alloys have higher acquisition and processing costs. Within this scope, this work present an analysis of the economic potential for the development of β-type titanium alloys applied in orthopedic implants, for that α, α+β and β titanium alloys were catalogued by type and price quotes, for those which are reasonable for orthopedic implant, with many distributors of raw material. Based on percent of the alloy composition, a relative price cost was determined for each alloy which was ranked by lower to higher cost.*

Keywords: *biomaterial, titanium alloys, economic potential.*

1. INTRODUCTION

Titanium alloys present good combination of mechanical and physical properties, including high strength/weight ratio and excellent corrosion resistance, making them desirable for a variety of applications, such as biomedical industry.

Titanium alloys can be divided in three groups: α, α + β and β alloys. Over a long period of time the Ti-6Al-4V alloy, principal representing of the α+β group, was extensively used as an implant material, replacing titanium commercially pure as a consequence of superior mechanical strength of the components made with this alloy. However, some researches has found that vanadium is toxic and can cause damage to the human health (Eisenbarth *et al.*, 2004) and aluminum can also be harmful, disrupting the biological system and causing local inflammation (Zaffe *et al.*, 2004) and may also be related to system disorders in the neurological system of the implanted person (Silva *et al.*, 2004).

β-type titanium alloys are composed of non-toxic and biocompatible elements, such as niobium, tantalum and molybdenum, as well as properties suitable for use as a permanent implant in the human body, such as corrosion resistance and biocompatibility. They exhibit several advantages over other types of materials used, since in addition to the high biocompatibility, these alloys still have adequate behavior in relation to the corrosion resistance, being immune to the body fluids. Due to their physical, chemical and mechanical characteristics, titanium β-type alloys show great potential to replace, in the near future, α+β titanium alloys in the manufacture of orthopedic implants. This fact has improved knowledge acquisition about the mechanisms and parameters that influence the microstructure of these alloys, which allows new materials design with ideal properties for orthopedic application.

For a material to be used as orthopedic implant, besides appropriate mechanical properties and biocompatibility, is necessary to have an accessible price. In that way, analysis of the economic viability of the materials used in the production of the implant materials become very important, because the cost of acquisition of such materials allied at the processing costs has direct relationship with the final cost of the orthopedic implant.

This work aims to carry out data collection and economic feasibility analysis for the development of β-type titanium alloys applied in orthopedic implants.

2. EXPERIMENTAL PROCEDURE

To carry out this study many titanium alloys were collected from books and journals. The data collected were selected mostly from studies that use titanium alloys as implants those alloys subdivided in agreement with the number of existent elements in its chemical composition and also in according with the present phases. In this work was not considered the subdivision of the alloys in near-α and near-β, being included respectively in the α and β alloys group.

Was realized the verification costs of each constituent element of the β titanium alloys, and this research was accomplished by researches in the internet. Calculation of the cost of each one of the alloys researched and the verification of the economic viability was accomplished in agreement with the proportion of each element that composes the alloy and also in agreement with the cost of acquisition of those elements.

Was also accomplished a research regarding the minerals of the which the metals are extracted and that are benefitted in Brazil, because the need to import the materials also increases the costs of acquisition of the same ones. Lastly was realized a study of the economic potential for the development of the β titanium alloys analyzed and selection of the five alloys that present smaller acquisition cost.

3. RESULTS AND DISCUSSION

In this section are presented the main results of this work.

3.1 Data collection

A large number of journals and books were selected in order to build a final table with a list of the principal titanium alloys. Those literatures were selected mostly from studies that uses titanium alloys as implants and also as general proposes. The data collected were organized by type and number of metals presents. Table 1 present a list of some titanium alloys that are selected divided in agreement with the phases that compose it.

Table 1. List of some titanium alloys divided in agreement with the phases that compose it.

Type	Alloy	Reference
α	Ti	(Umezawa *et al.*, 2016)
	Ti-7Al-0.08O-0.05Fe	(Ozturk *et al.*, 2017)
	Ti-6Al-4.5Cr-1.5Mn	(Wang *et al.*, 2016)
α + β	Ti-6Al-4V	(Hengel *et al.*, 2017)
	Ti-6Al-7Nb	(Niinomi, 1998)
	Ti-5Al-3Mo-4Zr	(Niinomi, 1998)
β	Ti-12Mo	(Zhang *et al.*, 2017)
	Ti-15Mo	(Zhou *et al.*, 2017)
	Ti-35Nb	(Hayama *et al.*, 2014)
	Ti-24Nb-1Mo	(Al-Zain *et al.*, 2011)
	Ti-25Nb-25Zr	(Dirras *et al.*, 2017)
	Ti-46Zr-8Nb	(Abdel-Hady *et al.*, 2007)
	Ti-29Nb-13Ta	(Niinomi *et al.*, 1999)
	Ti-30Nb-4Sn	(Fanton *et al.*, 2016)
	Ti-17Nb-1Mo	(Al-Zain *et al.*, 2010)
	Ti-14Nb-2Mo	(Al-Zain *et al.*, 2010)
	Ti-29Nb-13Ta-6Sn	(Niinomi *et al.*, 1999)
	Ti-7.5Nb-4Mo-2Sn	(Zhang *et al.*, 2016)

In agreement with the α alloys that they were verified, the principal α-phase stabilizer is aluminum. Such alloys also use neutral elements, like tin and zirconium and also β-phase stabilizers of the, being these in small amount, not being effective in the stabilization of this phase in α alloys.

Among the $\alpha+\beta$ alloys, was verified that some alloys that are commercial continue being studied by several research groups, as is the case of the Ti-6Al-4V alloy and that is used thoroughly in several areas, as in the aeronautical and automobile industry. Some researches related that some elements present in the $\alpha+\beta$ titanium alloys are harmful when implanted in the human body. Among the mentioned elements is the aluminum that can cause disturbances in the biological system and local inflammations (Zaffe *et al.*, 2004) and it can still be related to disorders in the human neurological system (Silva *et al.*, 2004). Some researches tell the vanadium is toxic and can to cause damages to the health of the implanted person (Eisenbarth *et al.*, 2004).

It was verified that among the β-type titanium alloys, some β-stabilizers elements are widely used in a varied the amount of the same ones and consequently varied also the degree of stabilization of this phase, in this case niobium, molybdenum and tantalum are included. Other alloying elements are also used in the stabilization of the β-phase, among them: vanadium, iron and chrome. These alloys group present also in its chemical composition the elements considered neutral, like tin and zirconium. The neutral elements do not affect the stabilization of the phases in the titanium alloys, but contribute to the increase of the mechanical resistance of the same ones.

3.2 Cost of materials

Before analyzing the cost of each element, it is necessary to evaluate the availability of the same in the market, and for that is necessary to evaluate the mineral deposits of the which the same ones are extracted. In a general way, how much rare in the earth crust is the element and the more difficult is the processing the same, more expensive its will be. In this way, how much harder is the extraction of the element of the ore, more expensive the metal will be.

As consultation base was used the Sumário Mineral (2015), being this a report of the Departamento Nacional de Produção Mineral, connected to the Ministério de Minas e Energia of Brazil. This summary is a compendium of existent metals/minerals and that are explored at the country. It was verified that although of Brazil to possess mineral deposits of the which the constituent metals of the titanium alloys are extracted, this country only benefits, in the form of primary metal, aluminum, tin and niobium. This fact contributes to the high costs of acquisition of the metals presented in this work.

In order to establish a price for those titanium alloys, it was decided to use a single provider that makes their information available to the online public. Table 2 shows the price relation of each material and its initial state, this information was obtained provided by Sigma-Aldrich (2017). As the supplier provides several states and prices, the adopted criteria for the choice were purity above 99% and lower price possible of US$/kg of material.

Table 2. Pure materials information (Adapted from Sigma-Aldrich, 2017).

Element	Price/kg (US$/kg)	Initial State	Purity (%)
Mo	1,147.93	powder	99.9
Nb	4,447.17	powder	99.8
Sn	597.86	powder	99.5
Ta	11,068.91	powder	99.9
Ti	645.02	sponge	99.5
Zr	7,366.00	bulk	≥ 99

In agreement with the presented values, it is verified that the titanium present low cost when compared to other metals, such as tantalum, niobium and zirconium that present high cost of acquisition. That difference in the costs can be explained by the availability of the metal in the earth crust and for the cost related to the improvement of the ore for extraction of the metal. Should also be added the import cost of several of the metals because a part of them is imported.

To obtain the cost of each alloy, the price/kg obtained, the data from the Table 2 were related to wt% of the forming elements of each β titanium alloy show in Table 1. In example, the binary alloy Ti-12Mo which has 12 wt% Mo and 88 wt% Ti. Using the prices in Table 2 of US$645.02/kg to titanium and US$1,147.93/kg to molybdenum, and multiplying by their respectively wt% of material, it is possible to obtain a final price of US$705.37/kg. Following this procedure, it was possible to obtain the results presented in Table 3, which contains the relative price for the titanium alloys presented previously.

A significant variation of the costs related to the Ti alloys was verified, varying from US$705.37/kg to the Ti-12Mo alloy, even US$7,242.81/kg to the Ti-46Zr-8Nb alloy.

Table 3. Relative price for the β titanium alloys presented previously.

Type	Alloy	Price (US$/kg)
β	Ti-12Mo	705.37
	Ti-15Mo	720.46
	Ti-35Nb	1,975.77
	Ti-24Nb-1Mo	1,562.57
	Ti-25Nb-25Zr	3,275.80
	Ti-46Zr-8Nb	7,242.81
	Ti-29Nb-13Ta	3,102.75
	Ti-30Nb-4Sn	1,783.78
	Ti-17Nb-1Mo	1,296.42
	Ti-14Nb-2Mo	1,187.38
	Ti-29Nb-13Ta-6Sn	3,099.92
	Ti-7.5Nb-4Mo-2Sn	949.36

3.3 Ranking

After determining the final price of the requested materials, it was possible to achieve a ranking of the five β titanium alloys that present good economic potential for use as an implant. Table 4 presents the ranking as well as the final price of the alloys.

Table 4. Ranking of β-type titanium alloys.

Position	Alloy	Price (US$/kg)
1	Ti-12Mo	705.37
2	Ti-15Mo	720.46
3	Ti-7.5Nb-4Mo-2Sn	949.36
4	Ti-14Nb-2Mo	1,187.38
5	Ti-17Nb-1Mo	1,296.42

It is verified in the Table 4 that the alloy that presented smaller proportional cost related to the materials that compose it was Ti-12Mo alloy. It is also verified that all the classified alloys present molybdenum in its composition, being not this element toxicant and not allergic (Zhou, 2011).

In a general way, it is verified that the metals used in the production of the titanium alloys are not obtained in Brazil, same possessing mineral deposits, the country does not make the improvement in the form of primary metal, being necessary the import of those metals, what elevates the cost of acquisition of the same ones substantially when it is produced alloys in laboratory scale, because the acquired amounts are small, the one that finishes hindering the researches in this area, because financial resources are scarce.

The researches with titanium alloys are necessary for the development in the biomedical area, and consequently the development of the production technology of orthopedic implants, therefore researching alloys with smaller acquisition costs with relationship to the materials that compose them, and also researching new processing route, do with that the costs of the pieces manufactured with such alloys decrease. It is known that when there is not development of new technologies, the country is dependent on others that developed it, being forced to import them when necessary.

After the analysis of the results obtained in this work, is it possible to affirm that the β titanium alloys present economical potential in relation to the cost of its elements if compared with the other alloys used for the same end. Besides once the β titanium alloys present mechanical and chemical properties favorable when implanted in the human body, what represents great improvement in the quality of life of the implanted person.

4. CONCLUSIONS

By performing the costs of each type of titanium alloys analyzed, it was possible to classify the five alloys with lower associated costs. These alloys present costs varying from US$705.37/kg to US$1,296.42/kg. Thus, it was found that β Titanium alloys presents economic potential in relation to the cost of their elements, when compared to the other alloys used for the same purpose, also presenting favorable mechanical and chemical properties to be applied as material of implant, which represents a great improvement in the quality of life of implanted person.

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