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REMAP

Correlation between rupture and yield torques in orthopedic screws

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Resumo:
Os parafusos são amplamente utilizados em ortopedia para a fixação de placas e barras na reconstrução de ossos fraturados e deformidades. Estes parafusos possuem um projeto controlado por meio de normas especialmente desenvolvidas para aplicações ortopédicas. Este trabalho apresenta uma correlação entre o torque de ruptura e o de escoamento para parafusos ortopédicos e também uma correlação entre a tensão e o torque de escoamento para a matéria prima e um produto, respectivamente. Obteve-se para parafusos construídos em liga de titânio TAV uma relação de cerca de 70% entre o torque de escoamento e o de ruptura. Neste caso, foi possível também obter-se uma relação entre a tensão de escoamento e o torque de escoamento, de forma a predizer o torque de ruptura final do produto a partir de uma propriedade da matéria prima.

Palavras-chave: Torque; tensão; parafusos; ortopedia; TAV.

Abstract:
The screws were largely used in the orthopedic area to fixation of plates and bars in reconstruction of bone fractures and deformities. These screws have a design controlled by standards specifically written for orthopedic applications. This work presents a correlation between the rupture and yield torques for screws products and also a correlation between yield strength and torque for the raw material and screw product, respectively. We have found for screws constructed in titanium alloy TAV a correlation of 70% from yield torque to rupture torque. In this case, it is also possible to get a correlation between yield strength and yield torque in order to predict the rupture torque for a final screw from a raw material property.

Keywords: Torque; strength; screws; orthopedic; TAV.

1. Introduction

There are few works in the literature regarding orthopedic screws, as well as standards to guide the construction and evaluation of them. The ISO 5832 standard serie establishes the tension parameters in traction mechanical tests for the raw materials and the ASTM F543 standard establishes the torsion parameters for screws products in order to be used as acceptance criteria for material and design project. Related with recent works two of them deserve attention. A.M. Kliauga et al. [1] evaluated a historical data from rupture torque and angle from several different Brazilian suppliers from 2007 January to 2008 May. Another, T. Gausepohl et al. [2], evaluated the pull out forces for screws during extraction from bovine and synthetic bones.

In this work, we reviewed the main criteria from the standards and literatures adopted as acceptance parameters for orthopedic screws during the design project. Additionally, it were discussed the results from a series of torsion and strength tests obtained from a controlled design project and with a commercial screws. From theses analyses we proposed a correlation between the rupture and yield torques for screws products and also a correlation between yield strength and torque for the raw material and screw product, respectively, in order to predict the rupture torque of the screw product.

Some materials are recognized materials for orthopedic applications manly those of the ISO 5832 standard serie. Regarding titanium the ISO 5832-3 standard (Implants for surgery -- Metallic materials -- Part 3: Wrought titanium 6-aluminium 4-vanadium alloy) presents the composition and strength limits of properties for products constructed with this alloy. Table 1 shows the tensile properties preconized by ISO 5832-3..

Table 1. Tensile properties preconized by ISO 5832-3

Parameter	Composition (%) w/w
Tensile Strengh	860 Mpa
Yield Strength	780 MPa
Elongation	10 %

Concerning torsion test standard the ASTM F543 - Standard Specification and Test Methods for Metallic Medical

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Bone Screws establishes the minimum requirements which can be adopted as an acceptance criteria for design product. In spite of the design screw related with pitch, thread and core diameters has improved a lot in the last few years the standard only establishes the criteria for a specific geometry of screws (HA, HB and HC) but the values are still useful for an engineering comparison evaluation. The main criteria are the yield and rupture torques and rupture angle. But also the insertion and removal torques and the pull out force evaluation are also asked for the standard. The insertion and removal torques have no mean for itself but when evaluated in a real product using situation it makes sense. During insertion into a bone the screw cannot failure which means that it cannot achieve the rupture torque, or even cannot achieve the yield torque or plastically deform. The catastrophic failure by rupture obviously implies on the loss of the product. While the plastic deformation cannot necessarily implies on the loss of the product but can became a problem during a extraction surgery or reduce significantly the fatigue lifetime of the screw.

Thus, if the insertion and removal torques were evaluated using a bone with same or higher density similar to a real situation the values can be compared to the yield strength, i.e., the higher torque after it the plastic deformation occurs. It is established a new criteria the insertion and removal torques cannot achieve the yield torque for the product. In this case the rupture torque and angle have a secondary importance but they are still valid as a process production control. Table 2 shows the acceptance criteria for rupture torque and angle established for ASTM F543

Table 2. Acceptance criteria for rupture torque and angle established for ASTM F543

Type and Size	Rupture Torque (Nm)	Rupture Angle (°)
HA 1.5	0.2	150
HA 2.0	0.35	150
HA 2.7	1.0	180
HA 3.5	2.3	180
HA 4.0	4.0	180
HA 4.5	4.4	180
HA 5.0	5.5	180
HB 4.0	1.3	90
HB 6.5	6.2	90

Finally the ASTM F543 ask for the pull out force test but does not establishes the acceptance criteria for the screws. This is because it is difficult clearly establishes a rule due to the fact that the bone quality varies a lot from patient to patient. T. Gausepohl [2] presented the pull out forces for several different screws. Figure 1 shows a graphic visualization for these data and an exponential fitting for them. The literature D.T. Reilly et al. [3] shows a reference study with a comparison between a bovine and a human bones. The results shows that the bovine bone is more resistant than the human bone. H. Kimura et al. [1952] (apud Reilly et al [3]) shows that the fatigue resistance of a bovine bone is 238MPa while according with K. Tsuda et al. (apud Reilly et al [3]) the fatigue resistance of a human femur bone is 157 MPa. M.C.M. Loffredo et al. [4] also compared the mechanical resistance for both bones and showed that the average rupture module of a bovine tíbia is 217MPa , Martin, RB et al [1993] (apud M.C.M. Loffredo [4]) while for human tibia is 214 MPa (S.M Snyder et al (M.C.M. apud Loffredo et al. [4]). Therefore, the values obtained for T. Gausepohl et al. [2] are rigorous and can be established as an acceptance criteria for pull out force. Any other screws that are not listed in the evaluated screws can be compared using the values obtained from the linear fitting, Figure 1. The same logic can be used to graphically express the rupture values from ASTM F543, Figure 2

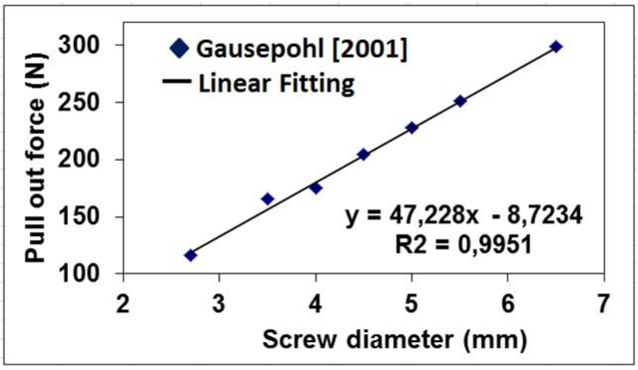

Figure 1. Graphically visualization from Gausepohl [2001] [3] data and a linear fitting for them

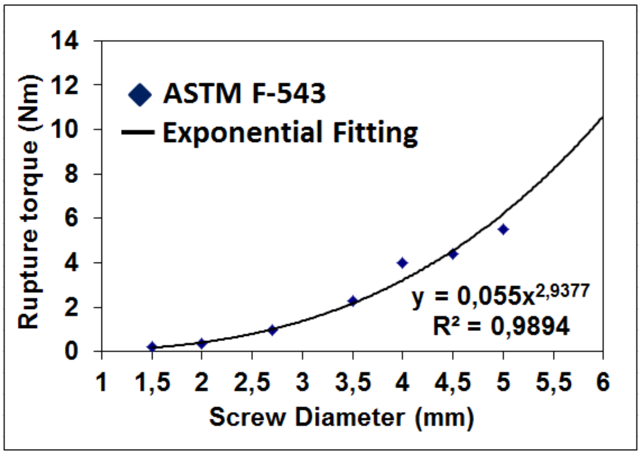

Figure 2. Graphically expression of the rupture values from ASTM F543

2. Methods

It were evaluated two serie of data from two different manufactories, here call company 1 and company 2. The names of the companies were intentionally omitted in order to preserve them.

The torsion tests in the screws of company were conducted in a screws with geometrical proportions between the diameters. Additionally, the screws were manufacture from the same raw material and fabrication process. The tensile properties for this raw material are known. The raw material from company 1 was certified as titanium alloy TAV (TiAl6V4), ISO 5832-3, with yield strength of 974MPa. It were produced screws with nominal diameters of 1.5; 2.0; 2.4; 2.7; 3.5; 4.0; 4.5 e 5.0mm. The screws were evaluated at CENIC, São Carlos/SP/Brazil, certified ISO 17025, according to ASTM F543. It were evaluated 5 screws from each diameter and the average value and standard deviation were used for the calculation.

The company 2 supplied screws in titanium alloy TAN (TiAl6Nb7), certified ISO 5832-11. The nominal diameters of the screws evaluated were 1,0; 1,5; 2,7; 3,5; 4,0 e 5,5mm. The torsion tests according to ASTM F543 were conducted at Centro de Caracterização e Desenvolvimento de Materiais (CCDM/UFSCar), São Carlos/SP/Brazil, and at SCITEC, Palhoça/SC/Brazil, both certified ISO 17025. It were evaluated 5 screws from each diameter and the average value and standard deviation were used for the calculation.

The data were graphically treated with Excel software with the values extracted from the torsion tests

3. Results and Discussion

Table 3 shows the results for torsion and tensile tests for company 1, rupture and yield torques and tensile yield.

Table 4 shows the values of torque obtained substituting chosen values in the diameter at Equation 1. If the Equation 1 represents the behavior of the rupture torque in function of the diameter of the TAV screws, represented in the continuous line in Figure 3, it is possible to assume that the values in the Table 4 are representative from this behavior. Figure 4 show the curve obtained plotting the values of Table 4.

Table 3. Results obtained for rupture torque yield torque and yeld strength

Screw Ø (mm)	Rupture Torque (Nm)	Yield Torque (Nm)	Yield Strength (MPa)
1,5	0,37	0,27	974
2	0,60	0,39	974
2,4	0,98	0,68	974
2,7	1,58	1,14	974
3,5	3,18	2,00	974
4	5,32	3,78	974
4,5	8,10	6,03	974
5	9,95	7,19	974

Figure 3 shows graphically the rupture torque in function of diameter for the analyzed screws. It is also possible to observe the exponential fitting equation (Equation 1) for the obtained values.

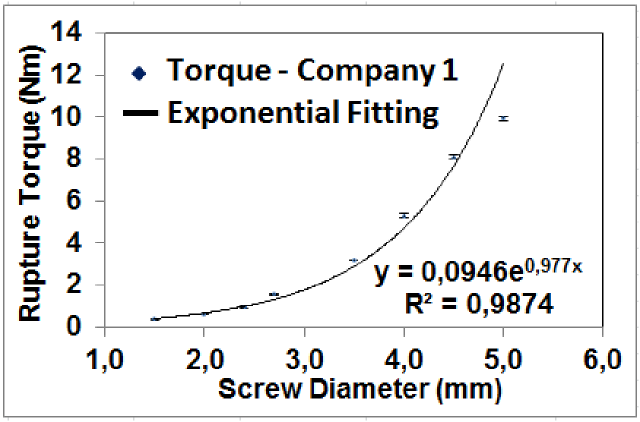

Figure 3. Rupture torque in function of diameter and the exponential fitting equation

rupture torque = 0,0946.exp(0,977.diameter) Equation 1

Table 4. Values of torque obtained substituting chosen values in the diameter at Equation 1

Screw Ø (mm)	Rupture Torque (Nm)
1,0	0,25
1,5	0,41
2,0	0,67
2,5	1,09
3,0	1,77
3,5	2,89
4,0	4,71
4,5	7,68
5,0	12,51

In the same way the yield torque can be evaluated. The Figure 5 shows graphically the obtained yield torque in function of diameter for TAV screws. Equation 2 represents this behavior. Table 5 shows the values obtained from Equation 2 and Figure 6 shows the graphically expression of these values.

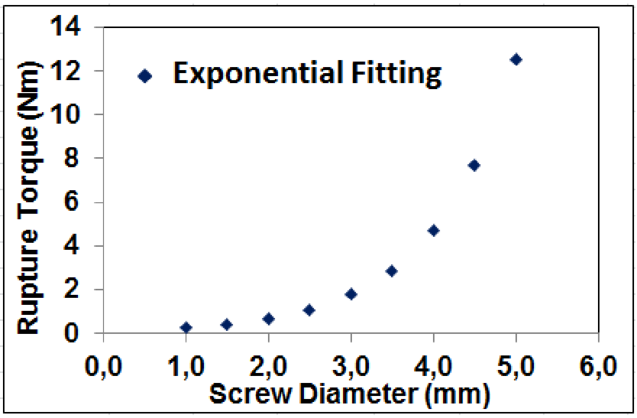

Figure 4. Graphically expression of the rupture values in function of diameter for Equation 1

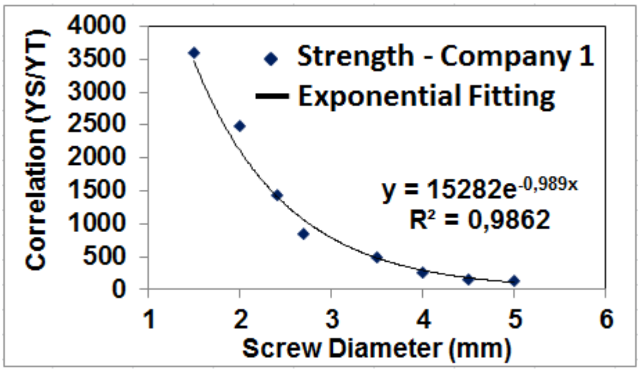

Figure 5. Yield torque in function of diameter and the exponential fitting equation

yield torque = 0,09637.exp(0,988.diameter) Equation 2

Table 5. Values of yield torque obtained substituting chosen values in the diameter at Equation 2

Screw Ø (mm)	Yield Torque (Nm)
1,0	0,17
1,5	0,28
2,0	0,46
2,5	0,75
3,0	1,24
3,5	2,03
4,0	3,32
4,5	5,45
5,0	8,93

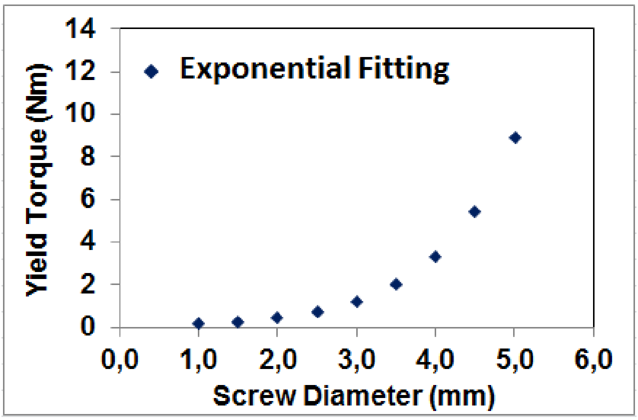

Figure 6. Graphically expression of the yield values in function of diameter for equation 2

Assuming true the values of Tables 4 and 5 and dividing the values one from each other it is obtained the values of Table 6.

It is noticed that - in spite of the mathematics necessary adjustments that will came with the refining of exponential fitting with a higher number of evaluated samples with several diameters, with the correction of the real transverse diameter – there is a correlation between yield and rupture torques by a factor of around 0.70, yield torque is about 70% of the rupture torque.

Table 6. Correlation between yield and rupture torques observed for Company 1

Screw Ø (mm)	Rupture Torque (Nm)	Yield Torque (Nm)	Yield torque/ Rupture Torque
1,0	0,25	0,17	0,68
1,5	0,41	0,28	0,69
2,0	0,67	0,46	0,69
2,5	1,09	0,75	0,69
3,0	1,77	1,24	0,70
3,5	2,89	2,03	0,70
4,0	4,71	3,32	0,71
4,5	7,68	5,45	0,71
5,0	12,51	8,93	0,71

Intending to compare this behavior, in a controlled project condition of same raw material, same geometry proportion, same fabrication process, with another screws, it was evaluated the data from Company 2. The results are showed at Table 7. Figures 7 and 8 show the graphically representation and fitting of the data and them respectively equation. Table 8 shows the correlation between both torques.

Table 7. Rupture and Yield Torque for screws from Company 2

Screw Ø (mm)	Rupture Torque (Nm)	Yield Torque (Nm)
1,0	0,056	0,032
1,5	0,235	0,150
1,5	0,258	0,181
2,7	1,260	0,780
2,7	1,040	0,653
3,5	**2,810**	1,970
4,5	6,210	4,150

Table 8. Correlation between yield and rupture torques observed for Company 2

Screw Ø (mm)	Rupture Torque (Nm)	Yield Torque (Nm)	Yield torque/ Rupture Torque
1,5	0,20	0,12	0,63
2,0	0,38	0,24	0,64
2,5	0,71	0,46	0,64
3,0	1,33	0,87	0,65
3,5	2,51	1,66	0,66
4,0	4,74	3,18	0,67
4,5	8,93	6,07	0,68
5,0	16,83	11,60	0,69

It is observed that, in spite of some adjustments suggested before, for the values obtained for Company 1, the behavior for the data from Company 2 are quite similar. Figure 9 showed both behaviors for both companies. It is also observed a small positive angle in both of them but is probably related with some necessary refining of the values.

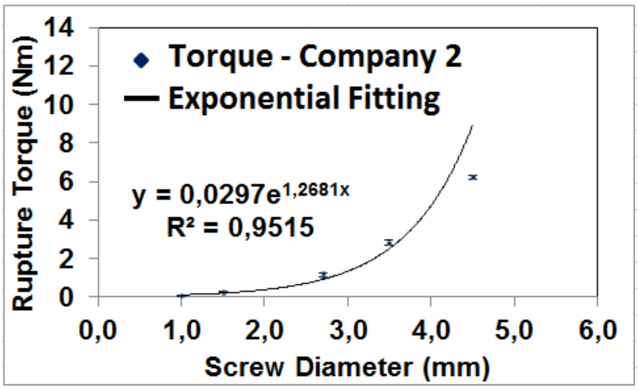

Figure 7. Rupture torque in function of diameter and the exponential fitting equation

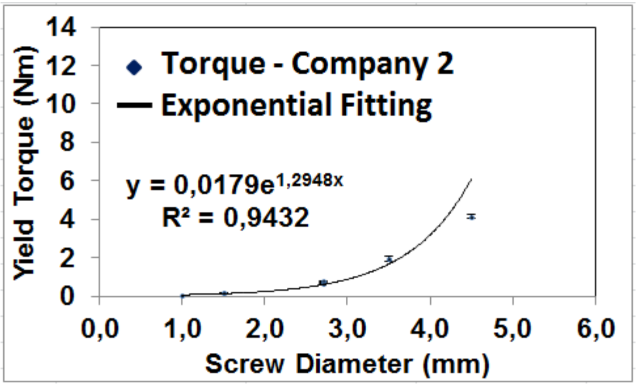

Figure 8. Yield torque in function of diameter and the exponential fitting equation

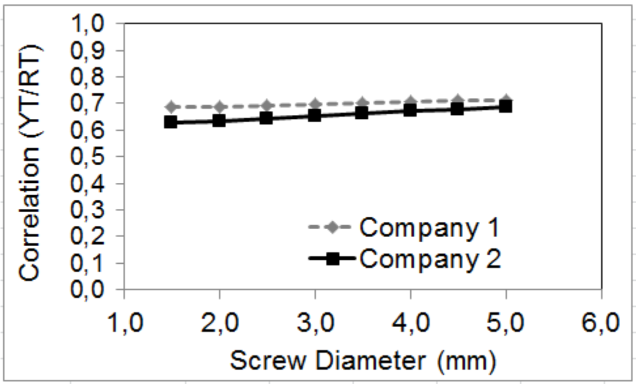

Figure 9. Comparison between both companies

Is interesting to mention that the screws for Company 2 are from different commercial lines which means that the geometry from one to each other are quite different but the behavior are quite similar too. This difference can be also associated with the raw material used.

Due to the fact that there is a correlation between yield and rupture torques and due to the fact that the yield torque is related with the elastic deformation of the material, it is possible to relate one from each other. The yield strength for raw material is 974MPa, as exposed before, Table 9 shows the relation and Figure 10 shows graphically this behavior.

Table 9. Correlation between yield torque and strength

Screw Ø (mm)	Yield Torque (Nm)	Yield Strength (MPa)	Yield Torque/ Yield Strength (Nm/MPa)
1,5	0,27	974	3607
2	0,39	974	2497
2,4	0,68	974	1432
2,7	1,14	974	854
3,5	2,00	974	487
4	3,78	974	258
4,5	6,03	974	162
5	7,19	974	135

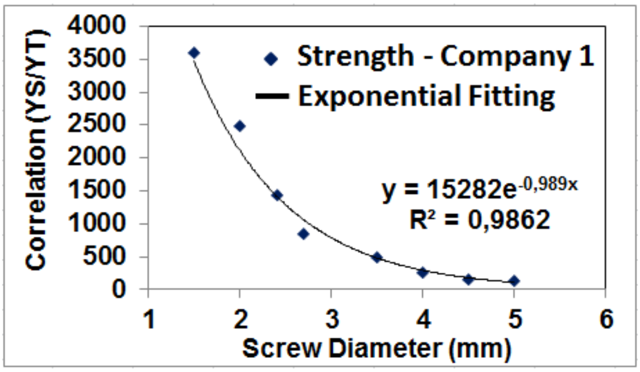

Figure 10. Graphically expression of the correlation and fitting equation

Assuming that there is a correlation, it is followed by Equation 3.

Correlation Factor = 15282.e(-0,989.diameter)   Equação 3

In this way for each diameter there is a multiplier fator of yield tension that became possible to infer about the yield torque and finally about the rupture torque. This inference can be used to define if some raw material is appropriated to produce a screw that match with ASTM F543.

For example, for the 3.5mm screw from Company 2 the tensile strength analysis showed a yield strength of 922MPa. Substituting this value at Equation 3 we have Yield torque = 922 / 480 = 1,92Nm and also a rupture torque = 1,92 / 0,70 = 2,74Nm, approved by ASTM F543 (2.3Nm is the acceptance criteria). The torsion test revealed that the result for the real rupture torque is 2,81Nm, quite similar, according to Table 7.

4. Conclusion

There is a correlation between yield and rupture torques for different screws analyzed. It is also possible to establish a correlation with the yield torque and strength in order to infer from the final rupture torque of a product.

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