Fretting Corrosion Performance Test of Spinal Screw and Rod Constructs: Effect of Stainless Steel –Titanium Combination

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Statement of Purpose: Spinal implants experience a combination of complex mechanical factors like cyclic loading, interfacial contact and micro-motions in an active physiological environment. These factors can lead to the disruption of passive oxide films on metallic surfaces, accelerating corrosion processes, decreasing structural integrity of implant and eliciting severe biological reactions in patients. Titanium alloy, stainless steel and cobalt chrome are most commonly used alloys for spinal implants. Surgeons may wish to mix components of different metals in order to use their best properties. However, very little is known about the effect of mixed alloy fretting interfaces on the propensity of spinal constructs to degrade due to fretting. The goal of this study is to determine whether alloy combination has a significant effect on the fretting corrosion response of spinal constructs.


Fig 1

Methods: The test set-up is similar to segmental spine model outlined by ASTM. To assess the material combinations (from all stainless steel to all titanium which has been anodized to a blue color), single rod-connector-screw construct (Fig 1) made of stainless steel and titanium alloy components (see table 1) is mounted on a custom designed construct (two delrin blocks to represent two vertebral bodies with no support between them other than the construct) where a single assembly is tested in the three principal axes of bending: anterior-posterior (A-P), medial-lateral (M-P) and axial twisting (A-T) each of which can give rise to fretting currents.

Material	Stainless Steel	Stainless Steel --> Titanium				Titanium
	1	2	3	4	5	6
	All	I	II	III	IV	All
MAS-1	SS	SS	SS	SS	SS	Ti
SS-1	SS	SS	SS	SS	SS	Ti
Rod 1	SS	SS	SS	SS	Ti	Ti
Connector	SS	SS	SS	Ti	Ti	Ti
SS1	SS	SS	Ti	Ti	Ti	Ti
SS2	SS	SS	Ti	Ti	Ti	Ti
Rod 2	SS	Ti	Ti	Ti	Ti	Ti
MAS -2	SS	Ti	Ti	Ti	Ti	Ti
SS-2	SS	Ti	Ti	Ti	Ti	Ti

Multi-axial screw (MAS-1, 2)
Set Screw (SS-1, 2)
Stainless steel (SS)
Titanium (Ti)

Table 1

The test set-up consisted of the spinal construct as working electrode, a carbon counter and a Ag/AgCl reference electrode immersed in phosphate buffered saline (PBS) solution of pH 7.4 at room temperature. The PBS only rises above the lower pedicle screw and rod-to-rod connector. The test set-up is mounted on a servo-hydraulic Instron system for application of the cyclic displacement (starting from 0.2 mm to 2.4 mm in 0.2 mm increment on a line of action 5 cm from the principal axes of the device). The currents were obtained by holding the potential of the test sample (with a potentiostat) fixed at –50 mV vs Ag/AgCl while monitoring the fretting current response. The samples were preloaded to -10 N prior to start of testing and a total of 540 cycles (3 Hz for 3 mins) were applied using the test frame at each condition (displacement and orientation). Load, displacement and currents were simultaneously acquired and used to determine displacement onsets and fretting current magnitudes. All tests are conducted in triplicate for each principal bending axis. Analysis of Variance (one way-ANOVA) and Tukey's post-hoc analysis is used to determine if statistically significant difference ($p<0.05$) exists between tested groups.

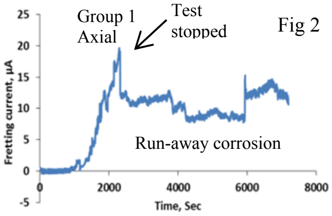

Fig 2

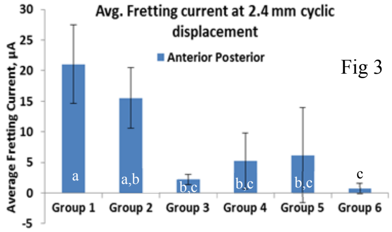

Fig 3

The letter (a, b and c) represent significant differences between groups in terms of average fretting current.

Results: Figure 2 shows typical raw data for group 1 (all stainless steel component), it is interesting to note that this group showed sustained post-test currents that continues unbated. Similar post-test currents were seen in all groups where stainless was present. This implies that stainless steel components are more susceptible to fretting initiated corrosion processes even after loading was stopped. As the construct takes on more titanium components, the recovery time for these post-test currents to return to pre-test baseline level gets shorter (data not shown). When construct is entirely Ti, the recovery is extremely fast (Group 6). Figure 3 summarizes the average fretting currents measured for each group for anterior posterior orientation at maximum displacement of 2.4 mm. The overall results shows that, group 1 and 2 (all or mostly stainless steel) have significantly higher fretting currents compared to other groups, and that group 6 (all Titanium) have the lowest fretting currents. For all groups, axial twist showed highest peak currents and lowest onsets (data not shown).

Conclusions: Fretting corrosion was observed for all materials groups in all principal bending motions. The most significant difference are that stainless steel devices are the least resistant to fretting corrosion reactions, and that there are significant sustained currents (continuing crevice corrosion reactions) seen even after fretting ceases (at the –50 mV potential examined) . All-titanium implants (Group 6) demonstrated the best response (lowest fretting currents) under the conditions of this test. Fretting currents were reduced as the system goes from all stainless steel to all titanium. Combining stainless with titanium does not show any galvanic-based acceleration of corrosion reactions.

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References: Serhan H, Slivka M, Albert T, Kwak D, The Spine Journal, 4 (2004), 379-387.

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