INTRODUCTION:
This study intends to examine the corrosion of retrieved 316L stainless steel lumbar plates to analyze the degree of corrosion and metal ion loss, and the relevant clinical consequences. The use of a lumbar plate and screw system, typically composed of stainless steel or titanium, assist in fusion between vertebrae. Stainless steel may be used because of its strong mechanical properties; however, stainless steel is more susceptible to corrosion than titanium, making it potentially more harmful to the body. Nickel and chromium ions, two main constituents of stainless steel, can be released into the body and deposited in periprosthetic tissue or carried by proteins to other parts of the body. These ions have been shown to have cytotoxic effects in vivo and possible adverse effects on the formation of a fusion mass. This can be potentially harmful to the patient or affect the outcome of the procedure.

METHODS:
A total of 113 316L stainless steel lumbar plates were retrieved from sixty patients at our institution; 13 male and 47 female of varying diagnoses and reasons for instrumentation removal. All plates were retrieved between 2002 and 2007 with an average implantation period of 1728 days, ranging from 78-4353 days. After careful cleaning, three different types of instrumentation were examined; 49 plates were Steffe (DePuy Spine, Raynham, MA), 41 were Dynalok (Medtronic-Sofamor Danek, Memphis, TN), and 23 were Isola (DePuy Spine, Raynham, MA). Based on visual inspection of the plates by research staff, each device was given a grade of corrosion; absent, mild, moderate, or severe. Plates receiving a grade of absent showed no evidence of corrosion. Plates exhibiting mild corrosion had some identifiable material discoloration comprising less than 10% of the surface area of the region proximal to the screws and washers. Moderate corrosion showed discoloration of 10-50% of the surface area with some material removal. Severe corrosion showed significant material removal and discoloration of more than 50% of the surface area, as shown in Figure 1.

The corroded areas were then analyzed through scanning electron microscopy and optical microscopy to identify types of corrosion, evaluate surface topography and survey the degree of metal loss. Energy dispersive x-ray spectroscopy analysis of corroded and non-corroded areas was performed on 17 plates with a corrosion grade of moderate or severe. Clinical data was collected, including BMI, duration of implantation, level of fusion, evidence of a pseudarthrosis, and original revision diagnoses.

RESULTS:
Overall, 72.57% of the plates showed corrosion. Corrosion was easily identifiable by metal loss and discoloration, the majority of which was observed at the screw-plate interface. There were 64 plates showing mild corrosion, 11 showing moderate, and 7 showing severe corrosion, as shown in Figure 2. Optical microscopy showed changes in surface topography of metal in corroded areas, and significant metal loss in plates with moderate and severe corrosion. Scanning electron microscopy of the plates revealed evidence of crevice and fretting corrosion, as shown in Figure 3.

Damage grade showed no significant correlation with collected clinical data. However, a significant correlation was found between the damage grade of the plates and type of device (p value of .00134). Isola had a significantly higher corrosion rate, while Steffe plates exhibited a significantly lower rate of corrosion, showing no severe corrosion.

Energy dispersive x-ray spectroscopy showed an increase in the weight percent of Cr and decrease in the weight percent of Ni in areas that were corroded when compared to areas that were not corroded. No statistically significant correlation was found between change in average Ni or change in average Cr content (between corroded and non-corroded areas) and clinical data, assigned corrosion grade, or implant type.

DISCUSSION:
This study examining 113 316L stainless steel lumbar plates shows that stainless steel plates have a high incidence of corrosion in vivo, predominately at the screw-plate interface in the form of crevice and fretting corrosion. A passive oxide layer, which typically provides a barrier from corrosion, can be removed by unintended micro-motion between washer and plate allowing for fretting corrosion to occur until the layer reforms. Furthermore, the very small gap existing between the plate and washer creates an environment ideal for crevice corrosion. A statistically significant correlation was found between device type and degree of corrosion, signifying that Isola plates have a higher rate of corrosion in vivo than Dynalok and Steffe instrumentation.

Both types of corrosion release Fe, Cr, and Ni metal ions and particulate into the body; most importantly the latter two which can be cytotoxic to the body. Analysis of differences in elemental weight percents between corroded and non-corroded areas indicates a preferential loss of Ni. Studies of stainless steel fretting corrosion have shown that metal ion release is dependent on the physiological environment; a proteinaceous environment, such as that found in vivo, may aid in the preferential loss of Ni, as compared to Cr. Metal ion release could have potentially adverse effects on formation and maintenance of the fusion mass. The presence of Ni ions specifically, have been shown to have an interfering effect on the signaling pathways involved in bone cell development.

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