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OXIDIZED METAL SURFACE DISINFECTION: A PERIODIC TREND

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Abstract
Because less than half hospital surfaces are clean, hospital acquired infections (HAIs) have resulted in an estimated 136 million rehospitalizations yearly. In order to combat this, scientists have studied metal surfaces' self-disinfecting properties. However, many studies have gaps: the oxides on the surfaces were not acknowledged; one type of stainless steel was tested; stainless steel was used as a control, despite not being an inert material; only two elements from the periodic table were tested. In this study, the disinfecting ability of oxidized transition metal surfaces (Ti, Cr, Mo, W, Fe, Cu, Ag, Au, Zn) and their dependence on atomic numbers, and stainless steels SS304 and SS316, are reported. The metals were allowed to interact with air for 24 hours, then their disinfecting abilities were compared to glass. Each surface got a 50 microliter nutrient broth drop containing *Escherichia coli* K-12 or *Micrococcus luteus*. A sample was taken from the drop every minute for 30 minutes for *E. coli* and every 30 seconds for 15 minutes for *M. luteus*, and cultured. The process was repeated thrice for each bacteria and metal. The only metal that reduced bacterial burden faster than glass was silver. An important pattern was noted: the trend of disinfection speed matched the trends of electronegativity, energy of second ionization, and electron affinity. While more data needs to be gathered, the similarity to pre-established periodic trends may aid in a better understanding of disinfection mechanisms of transition metals, and will provide the framework for creating efficient antibacterial alloys.
Keywords
Metal disinfection, transition metals, hospital acquired infections, self-disinfecting surfaces, d-elements.

ДЕЗИНФЕКЦИЯ ОКИСЛЕННЫМИ МЕТАЛЛИЧЕСКИМИ ПОВЕРХНОСТЯМИ: ПЕРИОДИЧЕСКАЯ ЗАВИСИМОСТЬ

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Аннотация
Бактериальное загрязнение поверхностей в госпиталях способствует распространению внутрибольничных инфекций, жертвами которых стали 136 миллионов пациентов (2024 г.). Опубликованные данные указывают на возможность решения этой проблемы с помощью самодезинфицирующихся металлических поверхностей. Однако у исследований в этой области есть существенные пробелы: не учитывалось влияние оксидов на поверхности; был изучен только один вид нержавеющей стали; для контроля использовалась нержавеющая сталь, хотя она не является инертным материалом; детально были исследованы всего два

металла. В данной работе представлены результаты изучения дезинфицирующих свойств окисленных поверхностей переходных металлов (Ti, Cr, Mo, W, Fe, Cu, Ag, Au, Zn) и двух сплавов нержавеющей стали (SS304 и SS316). Поверхности выдерживались на воздухе 24 часа при нормальных условиях, затем рост нанесённых на них микроорганизмов сравнивался со контрольными колониями на стеклянной поверхности. На каждую поверхность наносился образец питательного раствора с бактерией *Escherichia coli* штамм K-12 или *Micrococcus luteus* объёмом 50 микролитров. Из каждого образца с бактериями *E. coli* брали мазок с интервалом 60 секунд на протяжение 30 минут, а из образцов с бактериями *M. luteus* – каждые 30 секунд на протяжение 15 минут при идентичных условиях роста всех образцов. Бактерии с мазков выращивались в питательной среде в течение фиксированного времени в идентичных условия для оценки численности микроорганизмов. Процесс повторялся 3 раза для каждого металла и вида бактерий для получения набора данных для статистической обработки. Хотя из всех металлов, только серебро подавляло бактерии быстрее стекла, обнаружена зависимость скорости дезинфекции от электоотрицательности, энергии второй ионизации и сродства к электрону металлов, которая может помочь в понимании механизмов дезинфекции металлами и заложить основу для разработки антибактериальных сплавов.
Ключевые слова
Дезинфекция металлами, переходные металлы, внутрибольничные инфекции, самодезинфецирующие поверхности, d-элементы.

Due to many studies showing that less than half of surfaces in hospitals are clean [1], hospital acquired infections (HAIs) have resulted in 136 million rehospitalizations each year [2]. In order to combat the problem of microorganisms spreading on surfaces, scientists have studied metal surfaces for their self-disinfecting properties. However, these studies have not resulted in practically useful solutions or methods because of significant gaps in the research. In particular, the oxides and carbonates on the metal surfaces were not properly acknowledged; only one type of stainless steel that was tested; stainless steel was used as a control, despite its abilities to interact with microorganisms; in total, only two elemental metals from the periodic table were tested; each study focused on limited types of microorganisms, which does not allow to make conclusions about the feasibility of the disinfection for other classes of microorganisms [3, 4, 5]. The incomplete and nonsystematic studies have resulted in questionable conclusions, such as the recommendations to use copper-containing surfaces as surfaces able to reduce bacterial burden on them.

To adress the gaps, a systematic comparative study of the disinfecting abilities of a broad family of transition metals that takes into account the realistic state of their surfaces is proposed. Experimental data on the characterization of the disinfecting abilities of oxidized, carbonized for copper, metal surfaces and its dependence on atomic numbers of transition metals, Ti, Cr, Mo, W, Fe, Cu, Ag, Au, Zn, and stainless steels SS304 and SS316, are reported. The protocol included soaking each metal in vinegar, then allowing the metals to interact with air for 24 hours, then treating the metals with UV light, and finally, the metals' disinfecting abilities were compared to the control sample, glass. Each surface got a nutrient broth drop of 50 microliters containing *Escherichia coli* K-12, a gram-negative bacterium, or *Micrococcus luteus,* a gram-positive bacterium. A sample was taken from the drop every minute for 30 minutes for *E. coli* and every 30 seconds for 15 minutes for *M. luteus*, and cultured. Afterwards, each metal was wiped down with isopropyl alcohol. The process was repeated thrice for each bacteria and metal. The results then went through multiple statistical analyses.

The experimental data showed that the only metal that reduced its bacterial burden faster than glass was silver. This result contradicts the conclusions of previous studies that suffered from the

lack of comparison between different metals and the lack of acknowledgements of multiple factors. Moreover, an evident pattern was noticed after collecting data: the trend of the speed of disinfection matched the trends of electronegativity, energy of second ionization, and electron affinity for transition metals. While more data needs to be gathered, the similarity to three pre-established periodic trends may aid in better understanding the disinfection mechanisms of transition metals, and with more data gathered, will provide the framework for creating the most efficient antibacterial metal alloy surfaces, and possibly help in the development of metalloantibiotics. It also lays the basis for the data set that can be used for training of artificial-intelligence medical systems.

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