Discussion about the antibacterial activity of large-area graphene films produced by atmospheric pressure Chemical Vapor Deposition

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Understanding biological interaction with graphene films is essential to develop biomedical devices. In this context, few toxicity studies have been conducted on graphene, in particular regarding its antibacterial activity, showing however contradicting conclusions. One of the main reasons of the controversy is the nature and the properties of the various graphene-based materials. Graphite, graphene oxide, reduced graphene oxide or chemical vapor deposition (CVD) produced graphene can lead to dramatically different results when their impact on biological systems is studied.

The antibacterial activity of structurally flat graphene films is an interesting avenue to investigate because only a paper has been published showing that CVD graphene films on Cu, Ge or SiO_2 possess an antibacterial activity [1]. The antibacterial mechanism seems to be related to the electronic properties of the substrate with the hypothesis of electron transfer from the microbial membrane, via graphene, to the substrate which acts as an electron pump [1].

In the present study, we provide experimental evidence that rules out the electron transfer model as a mechanism explaining the presumed antibacterial activity of CVD graphene films. This calls for revisiting the problem in order to clarify the role of the substrate conductivity, keeping in mind that any study on antibacterial activity must meet the required standards in biology in order to be convincing [2]. For this purpose, we elaborated CVD graphene films on copper (Cu) and gold (Au) substrates. Either entirely or partially covering films were grown on the Cu surface whereas entirely covering films were transferred on the Au surface. The antibacterial activity of the different samples was tested on the Gram-positive *S. aureus* and the Gram-negative *E. coli*.

We showed the absence of antibacterial activity of large-area CVD graphene films on conductive (Au, Cu) substrates for *S. aureus* and *E. coli*. This result implies that the conductive character of the substrate has no influence on the viability of *S. aureus* and *E. coli* bacteria in contact with CVD graphene films. When a Cu substrate is used, however, the release of Cu ions from areas not covered by the graphene film led to an antibacterial effect which depends on the degree of graphene coverage [3].

The results obtained in this study have been confirmed independently by another study published very recently [4].

References

[1] Li J. et al., Sci Rep (2014) 4, 4359-4366.
[2] Kostarelos K., Novoselov K.S., Science (2014) 344, 261–3.
[3] Dellieu L. et al., Carbon (2015) 84, 310-316.
[4] Parra C. et al., ACS Appl. Mater. Interfaces (2015) 7, 6430-6437.

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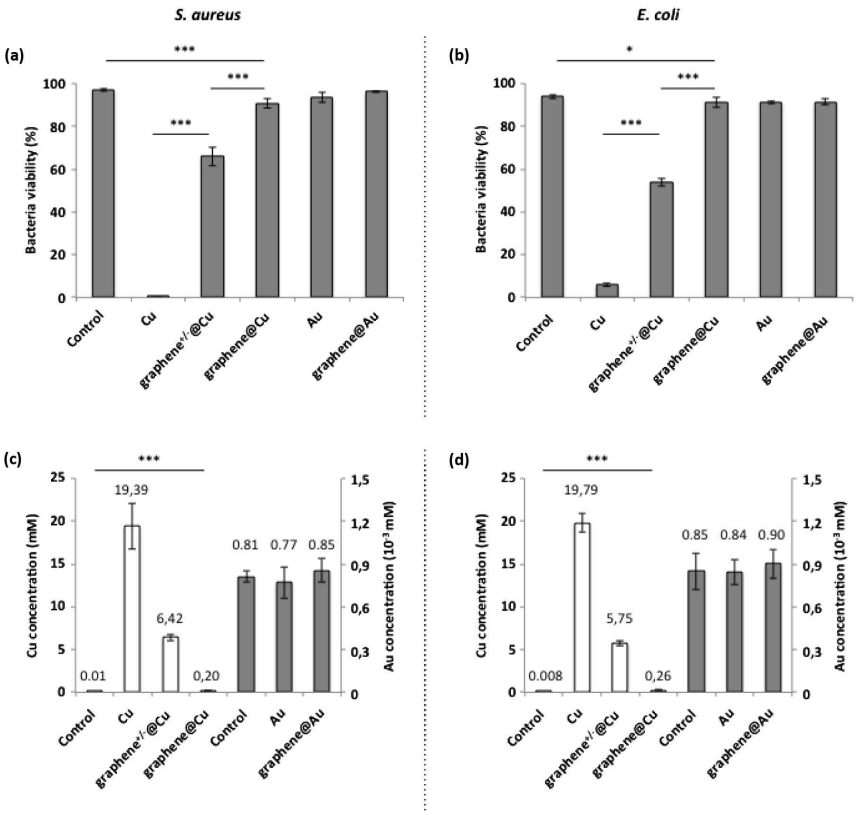

Figure 1: Graphene *per se* has no impact on S. aureus and E. coli viability. Bacterial viability was determined using the LIVE/DEAD assay after a 24 h incubation of S. aureus (a) and E. coli (b) on bare Cu, bare Au, graphene+/_@Cu, graphene@Cu and graphene@Au. Cu and Au concentrations were measured by AAS after incubating S. aureus (c) and E. coli (d) for 24 h under the same experimental conditions. Stars denote the statistical significance (p-values) in increasing order: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Error bars indicate standard deviation values.