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Electron Microscopic Characterization of Functionalized Multi-Walled Carbon Nanotubes and Their Interactions with the Blood Brain Barrier

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The structure and properties of pristine carbon nanotubes (CNTs) are well understood. However, CNTs in their pristine state are rarely used in real-world applications. Instead, CNTs are usually functionalized or otherwise altered to make them more suitable for applications e.g. to improve dispersion or to alter their electrical properties. Despite the huge number of publications on CNT functionalisation in recent years, the spatial distribution of these functional groups on CNTs, at the nanometer level, remains unresolved. This distribution has important implications for applications that rely on the interactions of the grafted groups with their environment (e.g. sensors, composites), or access to the nanoparticle surface for other species (e.g. supercapacitors, catalysts). The location of the functional groups and their relation to the underlying atomic structure also raises fundamental mechanistic questions about the functionalisation process.

A major reason that functional group distributions on CNTs have been poorly characterized to date is a lack of experimental tools which combine sufficient chemical and spatial resolution. The transmission electron microscope (TEM) provides a number of techniques which give access to both spatially- and chemically- resolved information, and has been instrumental in our understanding of atomic structure of defects, dopants and adatoms on graphene [1-2]. Here we correlate high resolution TEM imaging and electron energy-loss spectroscopy in the scanning transmission electron microscope (STEM-EELS) to map changes in electronic structure across individual acid-oxidized multi-walled carbon nanotubes (ox-MWNTs). Low-dose, monochromated EELS measurements reveal changes in the fine structure characteristic of ox-MWNTs, and density functional theory simulations show these features to be consistent with oxygenated functional groups, most likely carboxyl moieties.

CNTs are increasingly being developed both as neuro-therapeutic drug delivery systems and as neural scaffolds to drive regeneration across lesion sites [3-4]. Protocols have been developed to study CNT transport across the blood brain barrier *in vitro,* and uptake and translocation were found to be modulated by changing the surface charge of the CNTs.

References:
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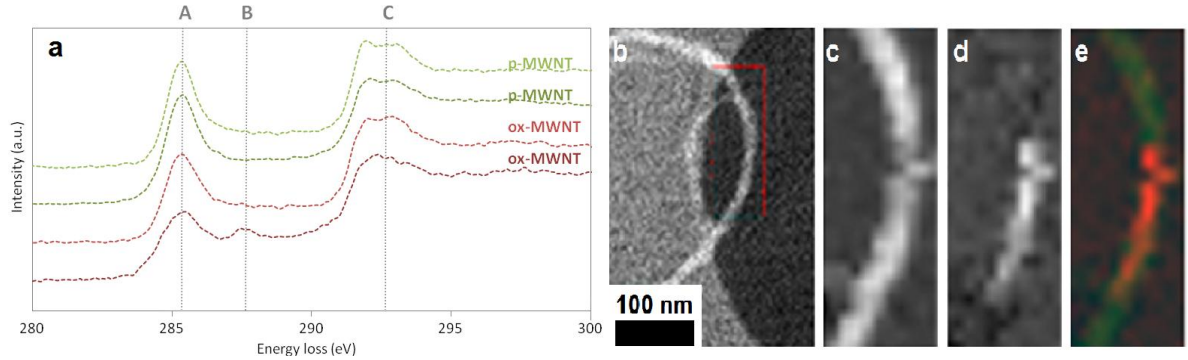

Figure 1. STEM-EELS maps of an individual acid-oxidized MWNT. (a) Typical EELS spectra from pristine (p-MWNT) and ox-MWNT samples, where peaks A and C are 1s-π* and 1s-σ* transitions, and peak B is characteristic of oxidized samples. (b) Dark field STEM image of an individual ox-MWNT, and chemical maps showing (c) the graphitic carbon signal, (d) functional peak and (e) combined false colour map of graphitic carbon (green) and functional group (red) signals.