ROBERT HOOKE – DISCOVERY
How the microscopic world was imaged in the 1600s

PROF. BRIAN J FORD, HON FRMS, HON FLS

INTRODUCTION

Scholars of the history of microscopy rarely have experience as microscopists. They may be well versed in the literature, and keen to rationalise the work of the pioneers, but the widespread failure to grasp the practical realities of microscopical observation gives rise to myths that become perpetuated over the decades. One of the most pervasive is the instinctive insistence that early microscopes produced images that were inevitably inferior, distorted by spherical aberration, compromised by chromatism and unrepresentative of reality. The inevitable concomitant is that pioneering microscopists exaggerated their drawings, falsified their findings, and imposed their own interpretations of a specimen in consigning it to paper. None of this is true, yet it pervades the received wisdom of the field [1].

THE PARADOX OF ROBERT HOOKE

When the Royal Society published Robert Hooke's great work *Micrographia* in 1665, they unleashed the power of the microscope to the public. Readers were enthralled. John Evelyn, the writer and founder member of the Royal Society, said it was 'one of the most delightful and instructive Treatises that I ever read', while Samuel Pepys, the diarist, concurred by describing it as 'the most ingenious book that I ever read in my life'. Readers remarked on the astonishing illustrations, which included large fold-out plates of a flea and a louse; the book became the talk of the town.

Was the vivid clarity of those detailed illustrations representative of what Hooke could actually see? No sooner had the book appeared, than sceptics expressed the opinion that he must be improving on nature and overstating what he observed. Within a year of the appearance of *Micrographia*, the prominent natural philosopher Margaret Cavendish, Duchess of Newcastle, published a critique of such discoveries [2] and widespread doubt was expressed over the veracity of the engravings that Hooke had published. Such scepticism has continued ever since.

Robert Hooke's alleged lack of realism in his portrayals of microscopic structures is regularly reported by scholars, who claim that he elaborated on reality while exaggerating and idealising his drawings to fit the aesthetic of the time. Nick Lane, who has published widely on the development of the microscope, has argued that early microscopes must have prevented observers from truly seeing reality, and he makes the prescient point that we still do not know what Robert Hooke could have seen.

THIS HISTORIC IMAGE reveals how microscope specimens from 1665 appear today. Professor Brian J Ford imaged Urtica diocia, the nettle, to provide a composite micrograph (right) matching the engraving in Robert Hooke's pioneering book Micrographia (left). Selection and orientation of the images provides a comparison between the engraved illustration and the modern photomicrograph.

I set out to resolve the matter.

For decades I have demonstrated that early compound microscopes generated indistinct images. Robert Hooke's microscope was incapable of revealing the details he describes in his writing, a paradox that has eluded historians of science for centuries. I have resolved the paradox: the answer lay in the fact that he didn't use his grand, beautifully embellished, desktop microscope for his keenest observations. As he mentioned in the Preface to *Micrographia*, it was the single-lensed simple microscope that Hooke utilised to reveal fine detail in his magnified images.

The pages to the Preface of *Micrographia* are not numbered, and scholars have overlooked the crucial comments Robert Hooke made on the 22nd page. In the final paragraph, he explains that he resorted to small, single lenses to determine fine detail. These, he wrote 'are exceedingly easily made' yet he found them 'very troublesome to be used, because of their smallness, and the nearness of the object'. However, Hooke explained that the single lens made specimens 'more distinct than any of the great Microscopes'. In fact, it was the simple microscope that provides the key to understanding the birth of microscopy, and Hooke's detailed design of a simple microscope is the one that the Dutch pioneer, Antony van Leeuwenhoek, was to adopt [4].

THE POWER OF THE SINGLE LENS

My recreation of Hooke's observations (and those of van Leeuwenhoek) showed just how detailed were the images generated by single lenses, and my experiments attracted much attention [5]. I demonstrated the results in presentations for the Royal Society, at Cambridge University, and

BIOGRAPHY

Brian J Ford has associations with the universities of Cambridge, Kent, the Open university (of which he is a former fellow), Leicester (former visiting professor) and Cardiff (where he is a fellow). For fifty years he has recreated pioneering microscopical observations, and now turns his attention to Robert Hooke in 1655 with a unique series of experiments. The author of some 35 books (many on the microscope) and hundreds of publications on the history of microscopy, Ford is also renowned as a lecturer, TV broadcaster, and research biologist.

ABSTRACT

Robert Hooke published his great work *Micrographia* in 1665. This remarkable folio-sized volume revealed the microscopical realities of insects, plants, crystals, fungi and fabrics to an astonished audience. Yet scholarly accounts misrepresent his endeavours. He is said to have exaggerated his published images, though we can now see that his studies were meticulous and clearly drawn. Comparison can be made with what he published, and what can be seen through a variety of microscopes old and new.

ACKNOWLEDGEMENTS

Dr Clive Jermy at the Natural History Museum, London, introduced me to Hooke's microscopy and microscopes in the 1960s. Dr Walter McCrone in Chicago Illinois, was among those encouraging and supporting my investigations during the 1970s, and my research in the 1980s was encouraged, among others, by Dr Peter-Hans Kylstra of Utrecht, Netherlands, Sir Andrew Huxley at the Royal Society, London, and Professor Denis Bellamy at Cardiff University. Mr Es Reid of Cambridge has recently created for me a selection of single lenses of the kind used by the pioneers, and aspects of this research have been supported by funding from the National Endowment for Science, Technology and the Arts (NESTA), the Linnean Society of London, the Spencer-Tolles Fund of the American Microscopical Society, and the Royal Society of London.

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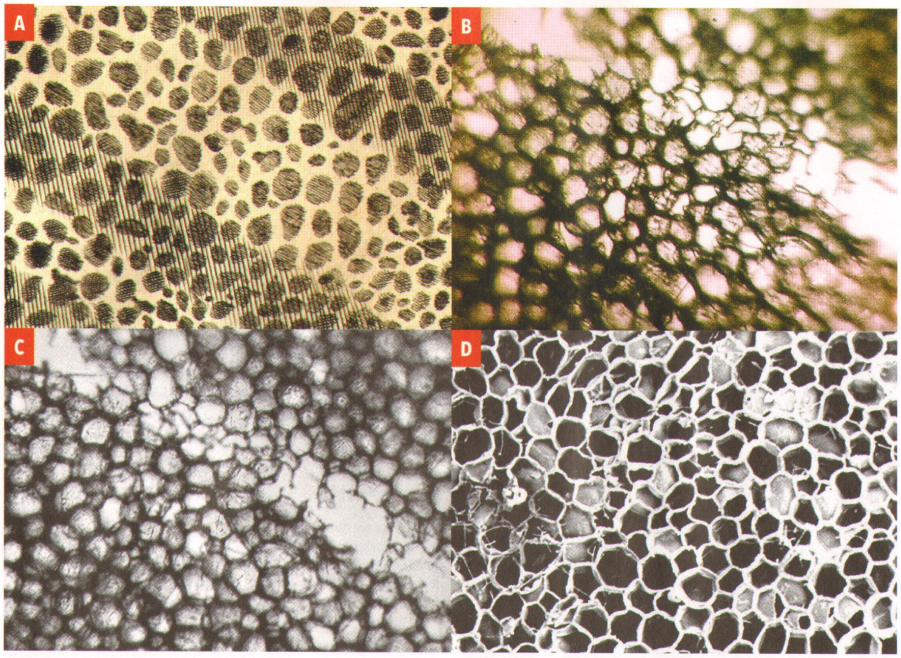

FIGURE 1: *A) Periodic shading in Hooke's illustration reveals a rising cut to produce thin regions for study, alternating with thicker zones providing support to the thin cork section. B) The Leeuwenhoek microscope in Utrecht, Netherlands, provides this view of his own hand-cut cork section, prepared in 1674 and mailed to the Royal Society. C) Identical cells from the Leeuwenhoek section of cork were located and photographed with a modern Leitz microscope for comparison with the single lens image. D) Cell walls from a seventeenth century cork show clearly when I imaged the Leeuwenhoek specimen with the Cambridge Stereoscan microscope at Cardiff university.*

extensively overseas.

As we have seen, it proved possible to obtain micrographs using present-day instruments, and compare those to images obtained with microscopes dating from the 1600s [1]. There can be no doubt that the early microscopists were able to obtain finely detailed images of surprising resolution; scholarship claiming that this was impossible can now be finally disabused. Yet one final demonstration has never been done: what would be the appearance of the same specimens as those studied in the seventeenth century under a microscope of today? Would the engravings so painstakingly supervised by Hooke represent our view of reality? Living specimens are vital and voluptuous, whereas the steel needle of the copper-plate engraver is uncompromising and sharp. Can the one truly represent the other?

I first published comparative micrographs of similar specimens with both old and new microscopes over fifty years ago [6] and the surprising clarity of the images revealed the capacity of single lenses to resolve details of microbial dimensions. International interest was widespread, and I presented the developing research in a range of presentations, and in major scientific publications [7]. I have since turned to the central topic that nobody had addressed: how accurate were the earliest illustrations?

ACCURACY AND REPRESENTATION

Current investigations have centred on Robert Hooke's published images. Specimens like those he portrayed – gnat larvae, cork sections, etc – were studied with a range of magnifiers. These included an early drum microscope, a design derived from the compound microscope used by Robert Hooke, a microscope attributed to van Leeuwenhoek, replica single lenses ground from soda-lime glass by Es Reid of Cambridge, present-day light microscopes by Leitz, Olympus and Radical, and the scanning electron microscope (SEM). The aim was to relate the range of disparate micrographs to the detailed engravings published in *Micrographia*. It was immediately apparent that single lenses generate images that are closely comparable to the illustrations by Hooke. The impact of artifice was slight; for the first time we can be assured that Hooke had faithfully represented what he could truly see. The first specimen chosen was cork, published as Scheme XI (facing page 115) of *Micrographia*. The specimens I used were small samples of the original sections that had been prepared by Antony van Leeuwenhoek in 1674, who was reprising Hooke's demonstrations. We thus had specimens contemporaneous with the microscope that had been used to observe them; there is no influence of present-day refinements in section cutting. Others have published images of modern cork sections that do not compare favourably with the precise perfection of those cut by Leeuwenhoek and Hooke [8]

The comparative images show how accurately Hooke was able to convey the microscopical appearance of cork through the medium of engraving. The varying thickness of his section can be seen to have been emulated by Leeuwenhoek, when he carried out the demonstration described by Hooke. A modern Leitz microscope vividly illustrates how well the single-lens image can approximate to what we would expect today. Finally, the scanning electron micrograph of the Leeuwenhoek section shows us unprecedented detail of the meticulous way it was prepared. Comparing the SEM image with the engraving from *Micrographia* confirms my contention that Hooke's images can convey remarkable realism.

We can compare a modern micrograph of fish skin from the sole (*Solea solea)* with the engraving, published as Scheme XXV (facing page 162) of *Micrographia*. The scales of the fish are seen as serrated tiles, overlapping in alternate rows. Robert Hooke embodies the crisp, fine detail of the specimen. The routine micrograph we'd take today shows the translucence of the fine spines that terminate each scale, and the intricacy of Hooke's figure provides further substantiation that he used a single lens, rather than a compound microscope, to elicit the fine structure.

Among the most vivid of the images in *Micrographia* are the engravings that Hooke published of insects. Each was shown in detail, with the most diminutive surface features – fine hairs and scales – portrayed with meticulous precision. Scheme XXVII of *Micrographia* (facing page 186) bears the image of a gnat larva. The mouthparts and eyes are immediately obvious, but closer inspection reveals the finest of segmental hairs. These larvae are easy enough to observe with the naked eye – they can be a centimetre long – and Hooke was always anxious to embody in his studies the finer structures that would elude casual examination. It was these details that made his engravings so compelling.

I scanned the engraved head of the gnat larva from one of my own copies of *Micrographia*, and then collected some larvae from a water-butt in the garden. Imaging one of these under a drum microscope created an image which showed that Hooke's proportions were clearly correct; the antennae and eyes could be closely correlated with the original engraving. However, the finer details could not be resolved, even though a drum microscope can provide an image that improves significantly on what Hooke could have observed with his own compound instrument. In comparison, I captured the image of a gnat larva with a single lens magnifying 60x. At once the fine details emerge. The most tenuous chitinous hairs adorning the anterior thoracic segments can easily be seen. There can be no doubt; Hooke must have employed a simple microscope for these studies, even if the compound microscope gave him the general disposition of the larval morphology. Finally, we can compare these images with the view obtained with a modern light microscope. The degree of detail we would expect to see in today's microscopical laboratory bears a close comparison with what Robert Hooke had published in 1665.

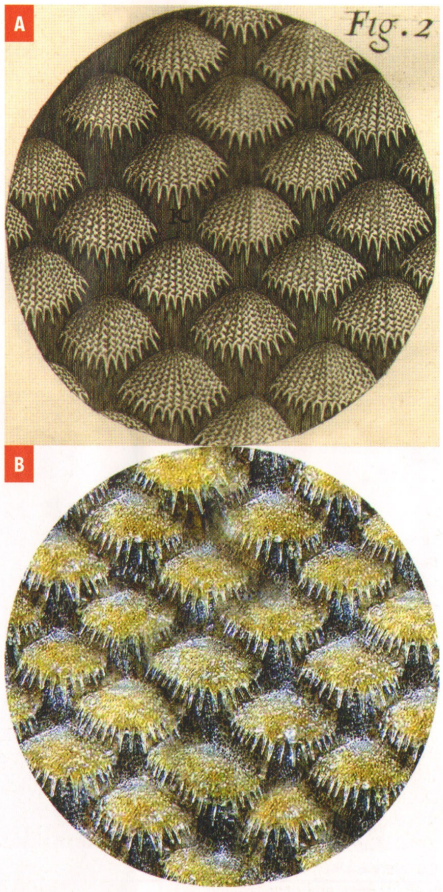

FIGURE 2: *A) Like many fish, Solea solea the common sole is covered with spiny scales produced in patterns like tiles on a roof. Hooke's engraving vividly captures this realism. B) A similar specimen prepared for Victorian microscopists can be viewed under a modern low-power microscope. It compares well with the image from 1665.*

CONCLUSIONS

Ever since Robert Hooke's great work *Micrographia* was published in 1665, scholars have doubted the veracity of his engravings. For the first time, microscopical images have been obtained of specimens of the same species viewed with disparate devices, and observation with a single

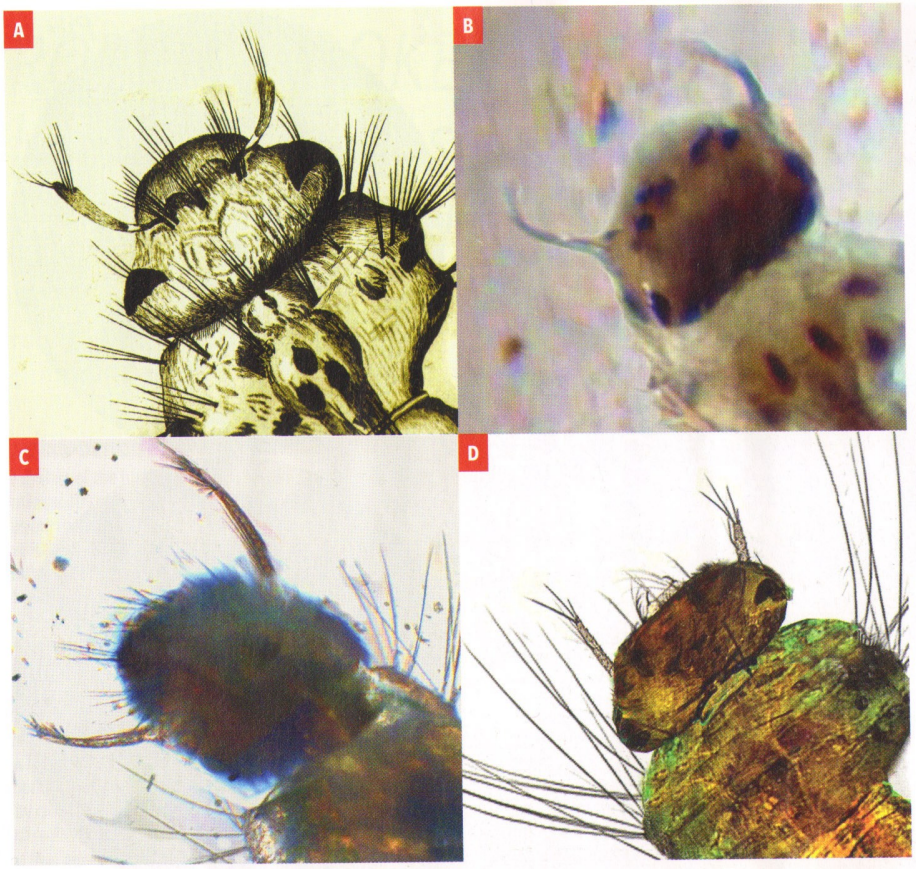

FIGURE 3: *A) Robert Hooke's book included remarkably fine detail in his microscopical illustrations of insects, as in this engraving showing the head and thorax of a gnat larva. B) The degraded image quality that was obtained with early compound microscopes is evidenced by this study of a similar specimen under a drum microscope. C) Details are revealed by examining a mosquito larva under a simple microscope. Chromatic and spherical aberration present minor perturbations to the image. D) Inspection through a modern light microscope confirms that the finest structural details incorporated in the Hooke engraving of 1665 were conveyed with remarkable accuracy.*

lensed, simple microscope has been shown to be the only means with which fine microscopical detail could then have been resolved. This itself is a crucial conclusion. Comparative micrography, using images of a given specimen with instruments ranging from simple microscopes to the SEM, now confirms that the doubts expressed by scholars over the visual veracity of Robert Hooke's engravings can finally be repudiated. Even though the uncompromising nature of engraving imposes rigid strictures on the conveying of the subtle vitality of biological specimens, Hooke's drawings clearly captured the essence of his subjects, and the engraver's skill gave the reader of *Micrographia* a vivid and representational insight into the reality of the microscopical world. These unprecedented images offer an abiding answer to the problems that have perplexed science for centuries. Finally, we can comprehend what Robert Hooke saw.

Article, and references available online at: analyticalscience.wiley.com/publication/microscopy-and-analysis