How Robert Hooke Observed the Flea in 1665

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Introduction

On January 21, 1665, in London, Samuel Pepys had been reading his newly purchased copy of *Micrographia*, replete with stunning engravings of the world under the microscope [1]. Pepys opened his diary and wrote that this was "the most ingenious book that I ever read in my life." He drew specific attention to the fold-out engraving of the flea, measuring some 20 inches (50 cm) long and commented, "The flea is so pretty a thing to look on through a microscope, that it makes me sorry I did not see it sooner" [2] (Figure 1).

It is an extraordinary illustration; many of those who purchased *Micrographia* cut out the page and had it framed to hang on the wall. The published illustration is exquisitely detailed and had been engraved from drawings made by Robert Hooke at the Royal Society. Hooke's compound microscope, manufactured by Christopher Cock in London, is featured prominently on the first page of this book — yet I discovered that his microscope could reveal none of the fine details in the engraving. Robert Hooke could not have seen what he portrayed [3].

A Quest for Detail

Within the pages of the preface to *Micrographia* lies the answer [4]. Hooke could not have used his famous compound microscope for high-power, detailed microscopy. It was not up to the job (Figure 2). Instead, he resorted to tiny single-lensed microscopes, with lenses ground from glass beads and mounted between metal plates. His description is clear and, next to his microscope illustration, he shows details of his lens-grinding contrivance and gives printed details of how he produced them.

Scholars have missed this fundamental consideration, and the pages from the preface are rarely cited in the literature because — being unnumbered — they cannot be quoted in a conventional reference. Hooke's account emphasizes the importance of these minute microscopes, explaining that "they magnifie and make some Objects more distinct then [*sic*] any of the great [that is, compound] Microscopes." The practical difficulty is that the object must be "plac'd very near" so the microscope is "very troublesome to be us'd, because of their smallness, and the nearness of the Object."

The increased clarity and resolution of a single, small lens is considerable, and the results have been greeted with enthusiasm by audiences of microscopists when presented at meetings of the Royal Society [5] and the Microscopy Society of America [6].

The Power of *Pulex*

Robert Hooke was fascinated by *Pulex irritans*, the flea he observed (and with which he would have been intimately acquainted). Even if it were not of importance to humanity, he wrote that this insect would merit attention for its "strength and beauty." Hooke was impressed by the flea's thoracic appendages, noting they could "spring them out to their whole length" in an instantaneous reaction of the third pair of limbs. Hooke accounted for the movement with a detailed paragraph that referred to each segment of the legs and attempted to account for the sequence of events that accompany the flea's prodigious leap, measuring 120 times its body length. As others have commented, a man jumping so far would reach 670 feet (over 200 meters).

The mechanism was exhaustively investigated by my late friend Dame Miriam Rothschild, who undertook to blend microscopy and mathematics to solve the puzzle (Figure 3). Her research was summarized in an influential book [7]. She later went on to publish a six-volume work on the Rothschild Collection of Fleas, which took over 30 years to complete. Miriam Rothschild became the twentieth-century authority on fleas, and she was actively involved in research until her passing at the age of 92 in 2005. The link — from Robert Hooke to Miriam Rothschild — spans more than three centuries and usefully unites natural philosophy with the curiosity of the modern mind. The techniques have evolved, sure, but the enticing challenge of intellectual pursuit remains the same.

Comparing Images with Reality

Robert Hooke was in awe of his flea, seen under the microscope. He commented poetically on its exoskeleton as "a curiously polish'd sable suit of armor, neatly jointed, and beset with multitudes of sharp pins." These minute features cannot be seen

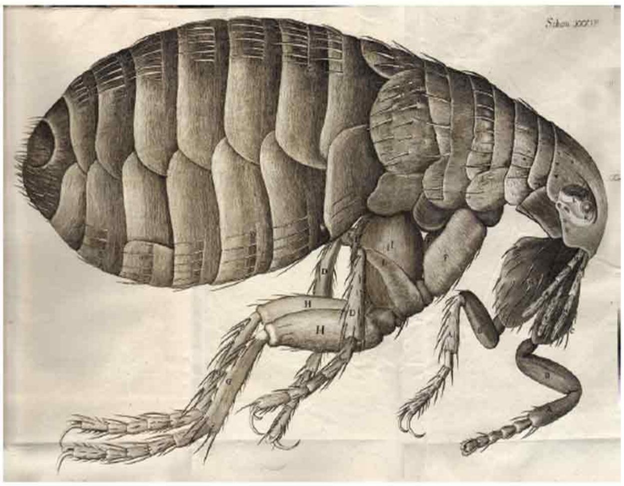

Figure 1: Robert Hooke's magnificent book *Micrographia*, published in 1665, includes this large fold-out engraving of *Pulex irritans*, the flea. The details are remarkable, yet they cannot be observed with the compound microscope he used in his investigations.

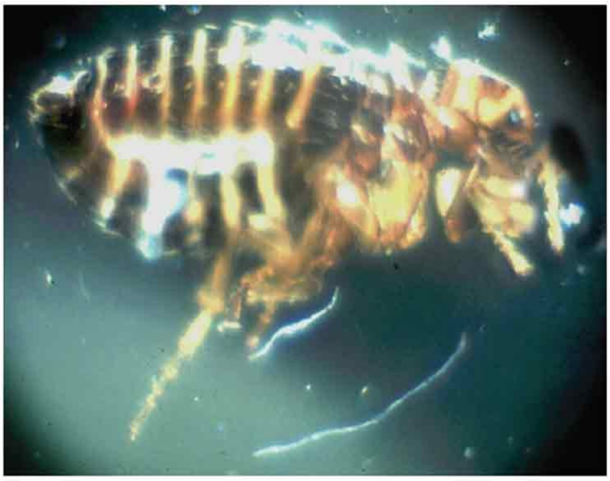

Figure 2: Early compound microscopes, of the kind available to Robert Hooke in the 1660s, can generate images like this of *Ctenocephalides canis*. There is little evidence of the "sharp pins" Hooke observed; the chitinous hairs that liberally adorn the appendages are invisible.

through an early compound microscope, though the single-lensed instrument revealed them all in detail.

Yet how realistic are the representations of Hooke's published illustrations, and how accurately are they truly images of life? For the first time I have now taken micrographic images through microscopes both ancient and modern for direct comparison with the published pictures (Figure 4). The photomicrographs were painstakingly captured through a range of magnifiers, including seventeenth-century compound microscopes and diminutive single lenses. I was fortunate to have access to small simple microscopes with lenses ground from spinel and manufactured by my late colleague Horace Dall of Luton, England, and others ground from soda-lime glass and mounted for me by Es Reid of Cambridge. In each case, no supplementary lenses were involved; the only refractive component between the specimen and the image-capture plane was the primitive microscope itself.

Ancient and Modern Micrographs

We can easily imagine where Robert Hooke obtained his flea. They were everywhere. *Pulex* specimens are less abundant today, and for the current investigations the dog flea *Ctenocephalides canis* was the specimen chosen. Its size, structure, and appearance are almost identical to that of *P. irritans*, except for pronounced pronotal combs that project backwards over the thorax and the ctenidium. This feature is instantly diagnostic of the genus, notably of *C. felis*, the cat flea. This species is also found in 90% of cases of dog infestation. *Pulex* and *Ctenocephalides* are widely confused across the web. A search for "human flea" under images will retrieve large numbers of photomicrographs and SEM images, which, the scholar is assured, are of *Pulex*; the unmistakable ctenidium immediately confirms this is wrong. The images are almost always of *Ctenocephalides.*

Using a seventeenth-century compound microscope gives a vivid view of a flea (Figure 4C). Yet no detail can be resolved. The dorsal ctenidium can be seen, overlying the first thoracic segment, though only the largest spines can be observed. Although the appendages are clearly visible, none of the finer structural features can be resolved. We can compare this view with the engraving of *Pulex* from Hooke's monumental book (Figure 4D). Far greater detail is included in this illustration; we can infer that a simple, single-lens microscope must surely have been utilized to capture the fine structure, since this is what Hooke, himself had recommended in his Preface.

Figure 3: The author with Dame Miriam Rothschild, who became the global authority on the flea and these insects' remarkable abilities to jump, a topic that fascinated Hooke. Size for size, a similarly endowed man would leap the equivalent of over 600 feet (200 meters).

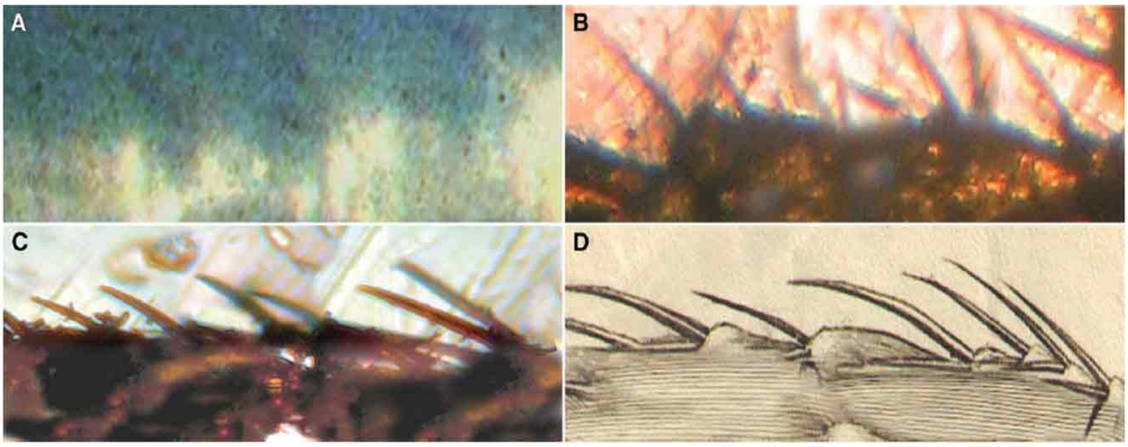

Figure 4: A, Selective enlargement of the micrograph in Figure 2 cannot resolve any of the fine details, or the surface hairs of chitin that characterize the appendages of the flea. B, In the decades following Hooke's demise in 1703, the Cuff compound microscope could provide improved resolution, though little detail can be studied. C, Using a single soda-lime glass lens created by Es Reid of Cambridge, and magnifying 160×, we can observe what Hooke saw with his simple microscopes. D, This extract from Robert Hooke's engraving of 1665 illustrates the remarkable similarity of the single-lens view to this image, as published in *Micrographia*.

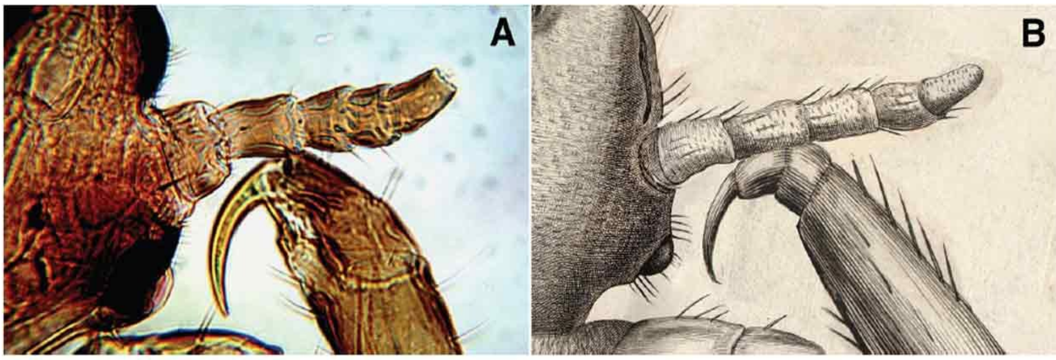

Figure 5: A, The eye, antenna and forelimb of a permanent preparation of the head louse *Pediculus capitis* imaged with a single-lens microscope by Horace Dall magnified 400×. In the 17th century, only a single lens could provide high levels of resolution. B, Robert Hooke had *Pediculus* engraved for the plate in *Micrographia*. Selected portions of the printed picture now allow scholars to make a direct comparison between the image that a single lens can provide, and details of the engraved illustration.

Conclusion

The micrographs confirm the deduction. The fine chitinous hairs with which the appendages are replete are invisible in a selective enlargement of the micrograph taken through a seventeenth-century compound microscope. After Robert Hooke died in 1703, John Cuff in London began to produce compound microscopes constructed of brass. With this improved instrument, some of the appendage hairs can be discerned, though an accurate portrayal would be impossible to obtain. The single lens, by contrast, reveals these finest structures in spectacular detail. If we compare this with a portion of the engraving in *Micrographia*, we can immediately see that this was the view that Hooke obtained with his simple microscope.

Hooke's ability to take what he observed and transfer it to paper stemmed from his abilities as an artist and designer. He acted as draftsman to Robert Boyle, was appointed surveyor for the rebuilding of London after the Great Fire of 1666, and designed the monument to the fire that stands to this day near London Bridge. Several churches also owe much to Hooke's designing talent.

We can compare a micrograph that I was able to take with a Horace Dall lens magnifying 400× (Figure 5A) with components of Hooke's engraving of the headlouse *Pediculus capitis*, which have been extracted from the engraving in *Micrographia* (Figure 5B). The representation is remarkable and confirm that, not only was Robert Hooke a consummately capable microscopist, but the engravings which resulted bear a remarkable resemblance to the specimens Hooke had studied, and which brought microscopy — for the first time — to a curious and incredulous public.

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