

Short Articles

THE PERFORMANCE OF SEVENTEENTH- AND EIGHTEENTH-CENTURY MICROSCOPES

by

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I. INTRODUCTION

TO COMPREHEND BETTER, and occasionally to elucidate, the writings, instruments or techniques of certain earlier workers in the medical sciences, the re-creation of the earlier experimental situation facing them, or "practical history", is a valuable means of supplementing the more conventional historiographical methods.¹ Thus it is nowadays difficult to realize the limitations of early microscopes, both optically and mechanically, but if such practical history is to be carried out, the constraints acting on earlier workers have to be understood. A few studies of the optical capacity of early microscopes have been carried out, as by Van Cittert² and by Bradbury,³ but such work requires extension if adequate parameters are to be established for choosing an instrument as being typical of its period. Accordingly, a number of instruments for investigation were selected from the Wellcome collection, together with seventeenth-century examples from the Science Museum. The range chosen was intended to supplement those described by Bradbury, and to complement them with some examples from the Continent.

II. APPARATUS

A major difficulty in using early microscopes is that they were made in many different sizes, often with small and awkward stages, and are now frequently unsteady in use. It is, of course, important to use some instruments as found if one is to appreciate the practicalities of their original employment, and this has been done. Equally, for purposes of testing optical characteristics in a fully comparative manner, some means is necessary to support any particular instrument in proper alignment with test slide or apertometer. It is also necessary to arrange for a camera to be readily attached in alignment. Once a range of instruments had been tested, it would be at least convenient to be able to use any of them under comparable conditions. A

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¹ 'Practical history. The role of experimentation in medical history', in E. Clarke (editor), *Modern methods in the history of medicine*, London, Athlone Press, 1971, pp. 358-375.

² P. H. Van Cittert, *Descriptive catalogue of the collection of microscopes in charge of the Utrecht university museum with an introductory historical survey of the resolving power of the microscope*, Groningen, Noordhof, 1934.

³ S. Bradbury, 'The quality of the image produced by the compound microscope: 1700-1840', *Proc. R. Mic. Soc.*, 1966, 2: 151-173.

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special universal stand was therefore devised, shown in plates 1 and 2. This has the merit of being relatively inexpensive, of being easily transportable, and of allowing any microscope body to be mounted in correct alignment with a modern unobstructed stage, with accessory eyepieces and other equipment, and with a 35mm camera.

The basis of the equipment is a Prior inverted microscope stand.⁴ This was obtained with an extra-long (60cm) column, to allow a large microscope of the Marshall type to be used with its lowest-power objective while still having space to attach the camera above. On this column is a dovetail slide, on which the various components are fitted. For our purposes, the only fittings required are the mirror, the stage (with attachable mechanical stage), and a number of condenser mounts as universal carriers. Both stage and condenser mounts have focusing incorporated. One of the mounts was machined out to accommodate the extension tubes of the Alpa 11e1 camera chosen as standard, thus allowing the camera to be attached within a few seconds without disturbing the setting of the microscope below. For the others, a number of discs having central apertures ranging from 12mm to 25mm were made, to allow virtually any objective to be held accurately in place below, with the eyepiece end similarly supported above. This allows any microscope body, with lenses in place, to be held in the optical axis without need of potentially-damaging clamping. Another carrier-mount is provided with a disc to hold a modern eyepiece, interchangeable with a small telescope of the kind used to set up phase-contrast objectives. In use, focusing is carried out roughly by sliding the stage relative to the microscope body, then clamping it and using its focusing: no difficulty has been experienced with even the highest powers. Once one is used to the apparatus, the numerical aperture of an objective can be determined with an Abbe apertometer within five minutes of picking up the microscope: the Abbe test plate can be photographed within a further two minutes. The only space required is about two feet square on any bench.

III. METHOD

The procedure typically is as follows. The stand is put on the bench from its shopping-bag carrier, mirror and stage being already in position. The microscope to be investigated has its body removed from its stand, and the objective(s) scrutinized to see if any obvious discrepancies exist: these would include odd mounts, apparently non-original parts, broken or missing lenses, etc.⁵ If all appears in order, the objectives are arranged with those of widest diameter (of lowest power) first, and a suitable diameter of disc is fitted to a mount. The body with lowest-power objective is placed in the carrier, and usually stays there without further support, because the interior of the aperture discs is slightly conical in shape, giving a self-centring and supporting effect. The standard Abbe test plate⁶ is put on the stage and roughly focused visually, after which the camera is fitted, with sufficient length of extension tubes to allow the

⁴ Supplied by W. R. Prior & Co. Ltd., London Road, Bishop's Stortford, Herts.

⁵ The degree to which non-original parts occur on an instrument is often difficult to decide. Only after handling many hundreds of examples of microscopes can one get a feeling for the correct workmanship of a period, and of a country within a period: however unsatisfactory it may be to those lacking such experience, this is the only sure guide, and the author is grateful to Gerard Turner for sharing his expertise in this field so generously.

⁶ Supplied by the Swiss firm of Wild Heerbrugg as a stock item, through their branches in most countries.

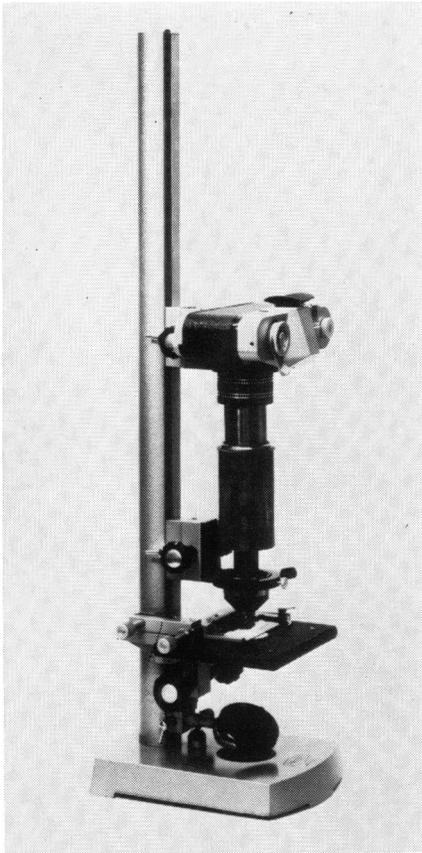


Plate 1

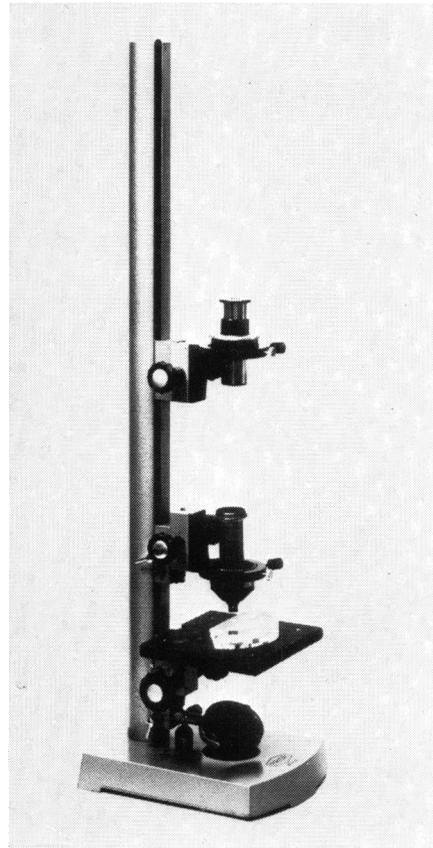
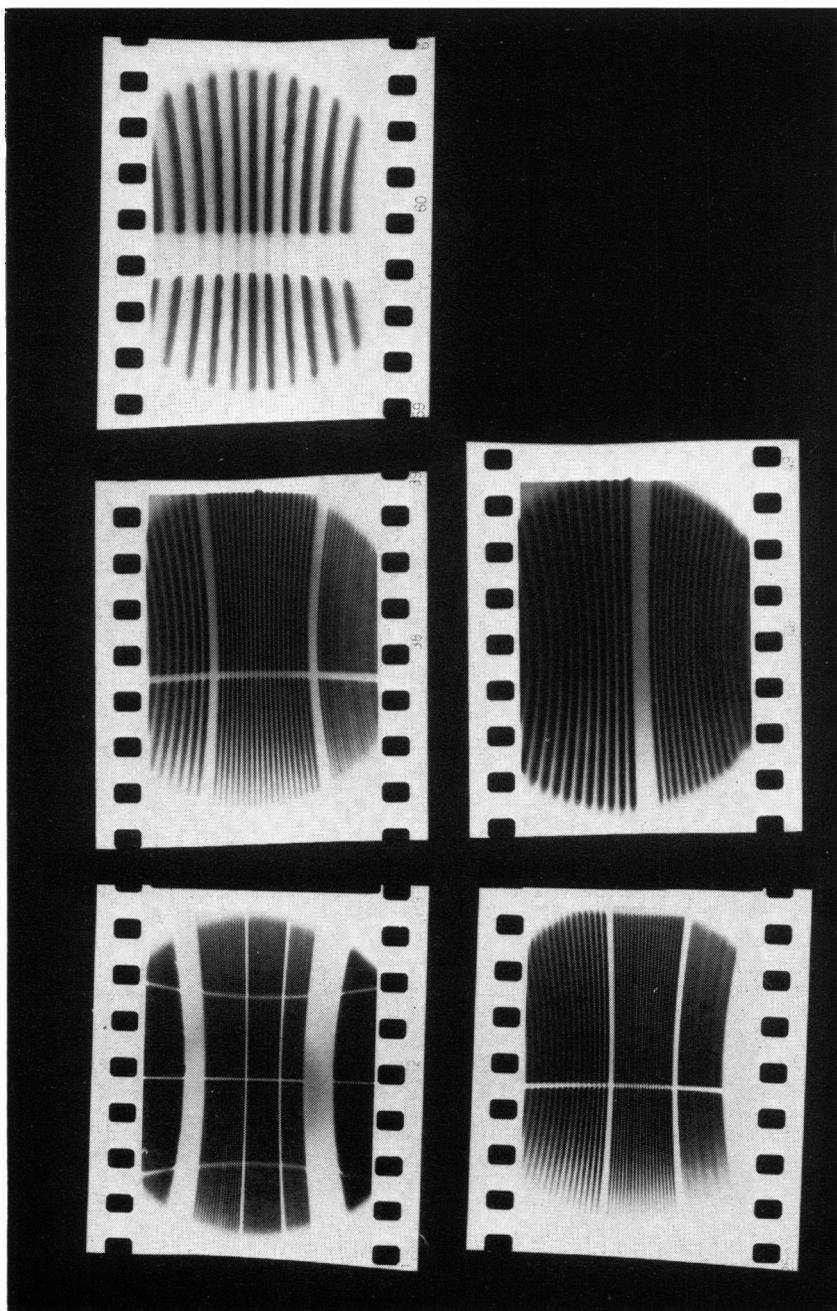


Plate 2

Plate 1. The instrument carrying a Culpeper body. The column, 60cm high, carries a mirror at the bottom, and above this a stage with focusing rack and pinion and attachable mechanical stage. A condenser mount with insert holds the objective end of the body tube of the instrument being investigated, the upper end being positioned by the camera's extension tubes. The length of these is chosen so as to put a full image circle, just clipped at its edges, on the viewing screen. The camera is an Alpha 11el, chosen for its first-rate mechanical construction, and its especially effective exposure metering.

Plate 2. The instrument arranged to measure the NA of the high power objective of the Culpeper microscope seen in plate 1. The substage mirror is not in use here, but the table lamp, not shown, illuminates the curved edge of the Abbe apertometer. Only the objective tube of the microscope is carried in a suitable disc. The apertometer is viewed by a modern eyepiece, with which the focusing telescope shown was interchanged to make the reading. The easy interchange of components is a feature of the equipment which has proved useful, allowing valuable instruments to be investigated on site without fear of damage.



12
26

38
48

60

Plate 3. Five test transparencies, printed as negatives to show typical results. These five were made with the Culpeper stand 253/1949 from the Wellcome collection. Frame 12 (top left) is from the lowest-power objective numbered 5, and shows the full width of the Abbe test plate bands, and more. Frame 26 (bottom left) was from objective 4, and shows all the bands. Frame 38 (top centre) was from objective 3, frame 48 (bottom right) from objective 2, and frame 60 (top right) from the highest-power objective 1. Even printed in black and white, the chromatic aberration is obvious, and uneven illumination, plus bad pincushion distortion also very plain. The original width of the film is, of course, 35mm.

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full image circle to be seen, with its edges just clipped (see plate 3). Three exposures are made, one either side of the indicated exposure, of the appropriate band(s) of the plate. This gives an objective record of the quality of the image, as well as the magnification of the system.⁷ The other lenses are dealt with in similar manner, a note being made of which band is being photographed. When all the objectives have been thus tested, their numerical apertures are measured. For this only the objective itself is required: usually it is possible to remove the nosepiece end of the microscope and use it as the mount, and this is desirable as objectives of the age being dealt with are not normally interchangeable between instruments. If it is impossible to disassemble the instrument, the objective alone is slipped into one of the aperture discs; as the arrangement is vertical, this is the only support and centring required. Above the objective a modern eyepiece is used to set up the apertometer, and then the reading is made with the aid of the phase telescope. The method is satisfactory for objectives having a numerical aperture exceeding 0.1, but for those of lower aperture a different method has to be employed.⁸

At the conclusion of the readings, the microscope is reassembled, an ordinary lens is put on the camera, and a photograph made of the instrument on the next frame of film to that used for the last test picture. In this way positive identification of the test frames is assured when the uncut film is returned by the processors. The pictures of the test plate are interpreted as described by Bradbury,⁹ to measure distortion as well as evaluate the quality of the image. The numerical aperture provides only some of the data: although it is a direct estimate of the best possible resolution of an objective, it is easy for a lens to have good resolution but very poor image quality. Having all the tests available as colour transparencies is a very important part of the procedure, for it allows direct comparison between all microscopes tested, and their placing on a five-point scale for quality.¹⁰ In using the instruments, standard

⁷ The test plate carries three bands of a silver deposit, as lines which alternate with spaces. The overall width of all the bands together in the sample used for this work is 5.746 mm: this total width allows the magnification of the lowest powers to be calculated from the test picture, at the same time as image quality is assessed.

The wide band is 1470 μ wide, one pair of light and dark bands being 98 μ wide. The mid band is 1220 μ wide, one pair measuring 64 μ . The narrow band is 765 μ across, one pair being 44 μ .

In making the picture with a particular objective/eyepiece, the camera is arranged to place most of the image circle on the film, just clipping the corners. This is an artificial arrangement, for in normal direct observing only part of this circle is normally visible on early microscopes. To compute the magnification, therefore, a standard procedure was adopted, enlarging the image circle to measure 90 mm in diameter, at which size it corresponds approximately to the direct visual picture. At this diameter, it is only necessary to measure whichever band was photographed to obtain a direct value for the magnification of the system.

⁸ For low values of N.A. the method described by E. J. Spitta, *Microscopy*, 3rd ed., London, Murray, 1920, on page 97 was adopted. This involves reading a target about 100 cm in front of the objective, and it was found convenient to use a second column from the Prior instrument, arranged horizontally on simple feet, on which to slide the existing components. As only the objective is required for this determination, problems of support are minimal.

⁹ Bradbury, *op. cit.*, note 3 above.

¹⁰ On this arbitrary scale, good quality is marked 1, and the worst 5. Good quality is similar to that obtained by a lens of similar power of the 1840s, that is with adequate but not perfect corrections. Bad quality is represented by a lens so poorly corrected that an image can only just be focused. Such a scale can only be applied if colour transparencies are to hand for direct comparison with each other and with a standard.

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illumination is an ordinary reading lamp with a 60-watt bulb. When early instruments were originally in use, the source of illumination would have been either daylight or a yellowish candle or oil flame: the modern light bulb is a convenient compromise which calculation shows will not affect the resolution of these early objectives in any significant manner.

IV. RESULTS

Throughout the work, when an instrument had variable separation of components affecting the magnification, a standard setting of 15mm from the fully-closed position has been adopted. The overall magnification of an instrument has been determined, and not the initial magnification of the objective alone. When a microscope was used in history, it was this total magnification which was significant, the other lenses being a constant factor, as in none of the instruments investigated was there any interchangeable eyepiece. With the total magnification known, of course, the numerical aperture of the objective has its established importance, allowing us to decide the degree of empty magnification present.

A. Seventeenth-century instruments

Nine instruments were examined, including two by Marshall, which are in concept of this century in spite of their being of later actual date:

1. SM 1928–822. A small instrument by Campani or Divini, said to have come from the university of Bologna via Pope Benedict XIV: has a field lens in addition to the eye-lens, and dates from the 1660s.

NA 0.06. Magnification 24x. Quality 2.

(The performance of this lens is remarkably good, with very little distortion and colour fringing: careful inspection has failed to reveal if it is or is not the original.)

2. SM 1954–290. A small tripod instrument, with draw-tube of green vellum. Dated about 1670.

NA 0.08. Magnification 23x. Quality 4.

3. SM 1888–172. Probably of Italian make, possibly from the 1680s, with a 3-lens eyepiece and single objective. The legs and collar are restorations, but the objective appears to be the original.

NA 0.10. Magnification 13x. Quality 3.

4. SM 1928–771. Dating from the 1690s, this small instrument has a two-part body, with tubes of vellum, giving a range of powers.

NA 0.08. Magnification 30x. Quality 3.

5. SM 1928–772. Made at the end of the seventeenth century, this is the only known signed English microscope (J. Mann) of that century. The power is variable, by separating the field and eye lenses.

NA 0.05. Magnification 10x. Quality 4.

6. SM 1938–709. Dating from the end of the seventeenth century, the instrument has a stage resembling that described by Bonanni.¹¹

NA 0.15. Magnification 13x. Quality 3.

¹¹ F. Bonanni, *Observationes circa viventia, quae in rebus non viventibus reperiuntur. Cum micrographia curiosa*, Rome, Hercules, 1691, see plate II, page 28.

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This is an unusually high value for numerical aperture, but inspection of the lens failed to suggest that it was not original.

7. SM 1925–132. Signed by Campani, the instrument dates from the end of the seventeenth century. Variable separation of eyepiece and objective gives variable powers.

NA 0.09. Magnification 23x. Quality 4.

8. Wellcome R17/1949. Dated about 1710, and signed by Marshall. Has four objectives, but lacks field lens and eyepiece.

1. NA 0.03. Probable magnification 8x. Quality 5.

2. NA 0.04. Probable magnification 12x. Quality 5.

3. NA 0.05. Probable magnification 40x. Quality 5.

6. NA 0.12. Probable magnification 95x. Quality 4.

9. SM 1928–773. Marshall signed and dated 1715. Four objectives:

2. NA 0.05. Magnification 13x. Quality 5.

3. NA 0.06. Magnification 42x. Quality 5.

4. NA 0.10. Magnification 51x. Quality 5.

5. NA 0.12. Magnification 78x. Quality 3.

The image quality of objective 3 was very poor, while that of objective 4 was even worse—far more so than that of any other early instrument ever seen by the present author. Objective 5, however, was rather better.

B. Eighteenth-century instruments

Sixteen microscopes were examined:

1. Wellcome 13/1949. A wooden tripod instrument, probably of German make, about 1710.

NA 0.09. Magnification 35x. Quality 3.

2. Wellcome 250/1949. Culpeper type, date about 1750, with five objectives:

5. NA 0.06. Magnification 15x. Quality 2.

4. NA 0.08. Magnification 28x. Quality 3.

3. NA 0.11. Magnification 39x. Quality 3.

2. NA 0.12. Magnification 61x. Quality 3.

1. NA 0.15. Magnification 98x. Quality 4.

3. Wellcome 19/1949. Culpeper type of about 1750, with one objective:

NA 0.09. Magnification 29x. Quality 4.

4. Wellcome 221/1949, Culpeper type, possibly of Dutch origin, about 1750.

NA 0.10. Magnification 35x. Quality 4.

5. Wellcome 5070. Culpeper type of about 1750.

NA 0.10. Magnification 31x. Quality 4.

6. SM 1928–792. Culpeper-Scarlett type, made about 1740, five objectives:

5. NA 0.05. Magnification 12x. Quality 4.

4. NA 0.08. Magnification 16x. Quality 4.

3. NA 0.10. Magnification 29x. Quality 3.

2. NA 0.12. Magnification 55x. Quality 3.

1. NA 0.14. Magnification 88x. Quality 3.

7. SM 1928–793. Culpeper type, probably made by Matthew Loft about 1735.

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- Has turned brass eyepiece instead of the usual wooden kind. Five objectives:
5. NA 0.07. Magnification 14x. Quality 5.
 4. NA 0.08. Magnification 18x. Quality 5.
 3. Quality so poor that no measurements could be made.
 2. NA 0.12. Magnification 64x. Quality 5.
 1. NA 0.16. Magnification 92x. Quality 5.
8. Wellcome 253/1949. Culpeper type, made about 1780. Five objectives:
5. NA 0.07. Magnification 12x. Quality 4.
 4. NA 0.08. Magnification 15x. Quality 4.
 3. NA 0.10. Magnification 28x. Quality 4.
 2. NA 0.14. Magnification 57x. Quality 3.
 1. NA 0.18. Magnification 95x. Quality 3.
9. Wellcome 223/1949. Cuff type, made about 1760 and signed by Passemont of Paris. Six objectives, one lacking its lens:
6. NA 0.06. Magnification 14x. Quality 4.
 5. NA 0.08. Magnification 18x. Quality 4.
 4. NA 0.10. Magnification 25x. Quality 4.
 3. NA 0.12. Magnification 44x. Quality 3.
 1. NA 0.24. Magnification 98x. Quality 3.
10. SM 1918–86. Cuff type, made by Ayscough about 1755. Two objectives:
6. NA 0.06. Magnification 8x. Quality 5.
 4. NA 0.09. Magnification 70x. Quality 5.
11. SM 1905–122. Cuff instrument, signed by him, made about 1750. Six objectives:
6. NA 0.04. Magnification 11x. Quality 3.
 5. NA 0.08. Magnification 23x. Quality 3.
 4. NA 0.12. Magnification 40x. Quality 3.
 3. NA 0.12. Magnification 45x. Quality 3.
 2. NA 0.14. Magnification 66x. Quality 2.
 1. NA 0.16. Magnification 92x. Quality 2.
12. Wellcome 12100. French compound instrument in wood, dated about 1750.
NA 0.06. Magnification 25x. Quality 5.
13. Wellcome 54/1949. German instrument, signed by Brander of Augsburg, dating from about 1750. Well made, with seven un-numbered objectives, two of them lacking lenses:
- a. NA 0.08. Magnification 12x. Quality 4.
 - b. NA 0.09. Magnification 19x. Quality 4.
 - c. NA 0.11. Magnification 31x. Quality 3.
 - d. NA 0.13. Magnification 49x. Quality 3.
 - e. NA 0.28. Magnification 95x. Quality 3.
- In spite of the high numerical aperture, the lens was of only moderate performance due to its poor corrections.
14. Wellcome 17721. Wooden tripod instrument, dated about 1760.
NA 0.08. Magnification 35x. Quality 4.
15. Wellcome 52/1949. Wooden side-pillar stand, said to be from the laboratory of

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Lavoisier, and dating from the 1780s.

NA 0.11. Magnification 45x. Quality 4.

16. Wellcome 65/1949. An unusual brass stand, signed by Blasi (Venice), dated about 1750.

NA 0.06. Magnification 29x. Quality 4.

V. DISCUSSION

The values for numerical aperture have been plotted against magnification for the two groups of instruments, in figures 1 and 2 (pp. 194–195). It is apparent that with a few remarkable exceptions, seventeenth-century microscopes offered only poor performance, unsuitable for resolving fine detail in histological studies: maximum resolving power would separate detail about 3μ ($3/1000\text{mm}$) apart, but with gross aberrations and very inferior image quality. In the eighteenth century matters had progressed hardly at all, although the stands then being used were often more convenient to handle: resolution might be better 2μ , but again with very poor quality and little brightness. For comparison, the average quality student microscope of today has a $\times 10$ objective often used at a total magnification of $\times 100$, with N.A. about 0.28, capable of resolving 1.3μ with *high* quality: and this is the low power on the instrument! It has to be stressed again that the microscopical world was seen only very imperfectly until the 1820s, with the honourable exception of Leeuwenhoek. The author has handled surviving examples of his microscopes, and there is no doubt that their results were not bettered until the 1820s, but as only Leeuwenhoek himself ever had access to them for scientific work, they affected no one else's.

The picture here outlined has been taken further by Turner,¹² who discusses the progress made in the nineteenth century. So far as work in recreating seventeenth-century results is concerned, choice could fall on a Marshall microscope as being typical in quality and fairly robust in construction. Similarly, for the eighteenth century, a Culpeper-type instrument would be representative. In each case, of course, the optical parameters would have to be established as being within the range herein reported, as individual lenses can vary widely in performance.

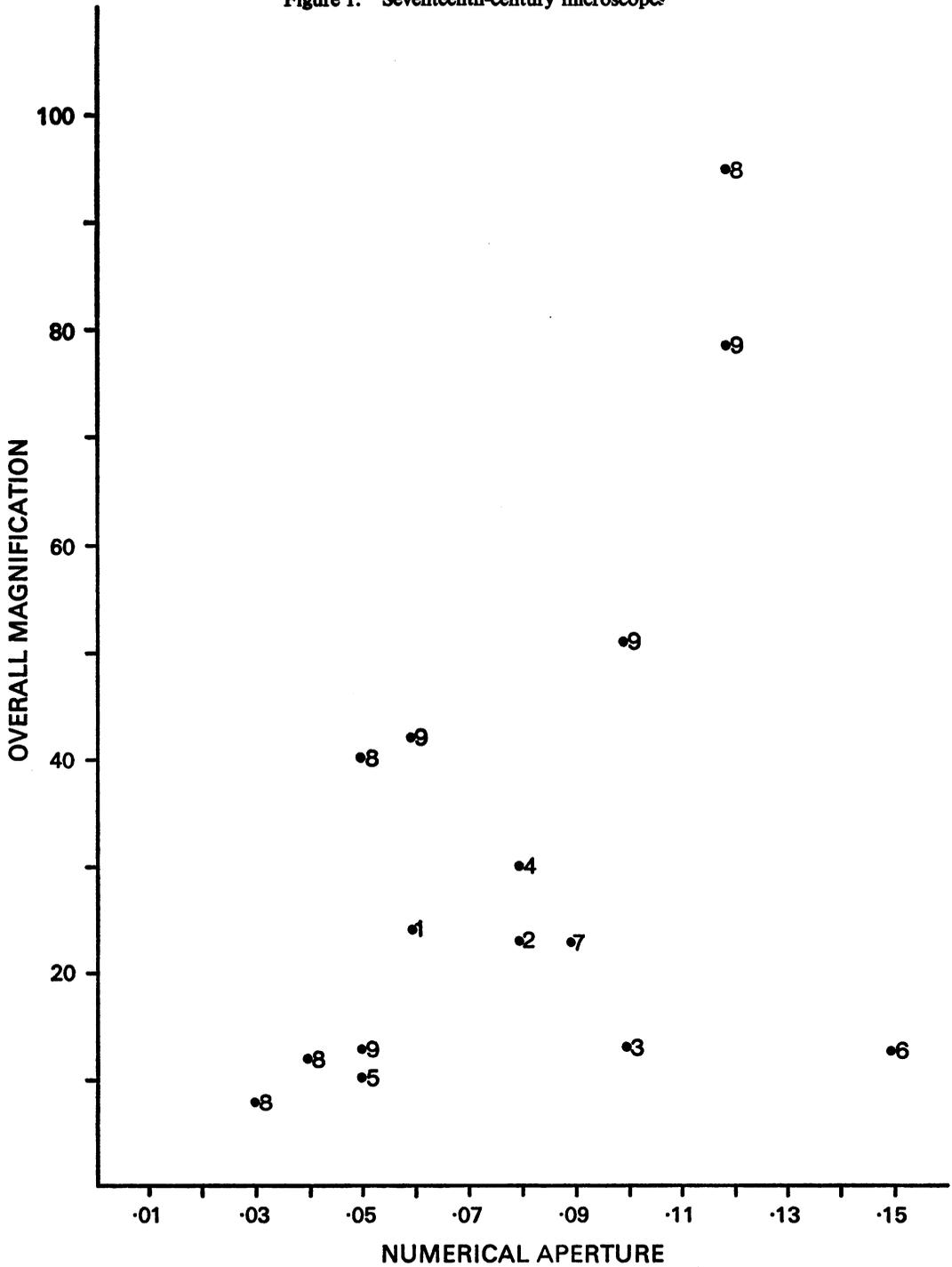
SUMMARY

To understand the limitations of early microscopes available for "practical history" investigations, assessment of the optical performance of a range of instruments was required. To facilitate this a universal supporting stand was devised and is described. Results from measuring optical quality of nine seventeenth-century and sixteen eighteenth-century microscopes are given, with comments on their suitability for histological work and on the variability in quality.

¹² G. L'E. Turner, 'The microscope as a technical frontier in science', *Proc. R. Mic. Soc.*, 1966² 2: 175–199.

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Figure 1. Seventeenth-century microscopes



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Figure 2. Eighteenth-century microscopes.

