Basic Principles of the Surgical Microscope

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1. Basic Definition

The human eye functions basically the same as a camera. A basic surgical microscope is an optical instrument, mechanical, electrical or both, consisting of a combination of lenses which provide the surgeon with a stereoscopic, high quality magnified image of small structures with the surgical area.

A key characteristic of any surgical microscope is its design. In order for the surgeon to concentrate on the surgical procedure, the microscope is designed such that the surgeon remains comfortable and free of eye strain. This design also frees both of the surgeon's hands to operate.

2. Magnification

The magnification of an image is a relative value and has to do with the size of an image as projected onto the retina of the eye (or onto a piece of film in the case of a camera). Therefore, the magnification of an image is increased by simply decreasing the distance between the eye and the object in question.

Figure 1. Demonstrates this basic fundamental in its most simple form. The object being observed, an exclamation mark, is moved closer to the viewing eye and the size of the reflected image on the retina is increased. When the retinal area covered by the projected image is doubled, the magnification would be considered to be 2x or two times magnified over what it was previously, taking the previous position as a base value. Obviously, a base value would always have to be set in order to determine the magnification factor.

In the case of the human eye and the use of optical aids, such as telescopes, binoculars, etc. the base value is simply the size of any object as it projects onto the retina from a specific distance without the help of the optical aid.

With the use of the optical aid, and without changing the distance value, the size of the image of an object can be increased on the retina as seen in Figure 2. The amount of increase, then, becomes the magnification value of the particular optical aid, whether it is a telescope, binocular or microscope. A 7x binocular (or “field glass”) has the fixed value of increasing by seven fold the dimensional proportions covered by objects on the human retina.

In this example, the size of the exclamation mark on the retina is increased considerably without moving the object closer to the eye. In other words, the optical aid increases the image size on the retina without the need to reduce the eye-to-object distance to get the desired effect.

2.1. Illumination/Magnification

The microscope illuminator transmits light to illuminate the surgical area. This light, like all light, can be varied. One way to vary the light, all other things being equal, is to change the voltage to the light bulb. Most microscope floor stand power supplies have a provision to vary the light intensity by this method. Under the microscope, a specific amount of light will be projected and any change made in microscope magnification will have no effect on the amount of light being projected from the microscope.

Changes made in the magnification of the microscope do, however, increase or decrease the amount of light which will be projected back through the microscope and onto the retina of the eye of the viewer.

In Figure 3, Detail A, we see an eye observing an illuminated area through a microscope set a low power (wide field-of-view). At this low power setting most of the illuminated area is projected to the retina and, therefore, so is most of the reflected light. In Figure 3, Detail B, the microscope is changed to a higher magnification (smaller field-of-view) and it is easy to see that of the total area illuminated by the
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Figure 1. Basic Components of the Human Eye

Figure 2. Magnification in the Eye Using an Optical Aid
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Microscope, only a small part of that area is viewed by the retina and only a small amount of the total reflected light is projected to the retina. The eye would have, in this instance, perceived a dimming of the view as the microscope magnification was increased. Therefore, any increase in microscope magnification will be accompanied by a decrease in the brightness of the image as it hits the retina.

Conversely, a decrease in microscope magnification will create an increase in the brightness of the image going to the retina. Several manufacturers, however, have gone to great efforts to minimize this by using ultra-wide, multi-coated optics. Therefore, this effect will be difficult to notice, if not impossible.

### 3. Definition of A Microscope

A microscope is nothing more than a monocular or binocular with a close-up lens (**Figure 4**, Detail A). A binocular is simply mounted side-by-side for stereoscopic vision. In the binocular concept, the length of the telescope becomes condensed by the use of prisms. If you go to a department store and ask to see both a 20x telescope (**Figure 4**, Detail B) and a 20x binocular (**Figure 4**, Detail C), you will, upon close observation, notice that both perform the same job. The 20x binocular consists of two 20x telescopes hinged together.

Since telescopes tend to be used mostly for astronomical usage, there is no need to use prisms to shorten their length. Such prisms can cause light loss which is most undesirable in low-light astronomical use. However, a binocular, or field glass, is for everyday use a sporting events, hunting trips, etc. In the case of a binocular, then, light is not considered a scarce quantity and prisms are used to bounce the light back and forth inside the body of the unit. This provides the necessary focal length to achieve magnification but keeps the overall size of the unit as compact as possible.

In **Figure 5**, we see again the components of the basic stereo microscope, the binocular head, and the objective lens. This microscope, however, contains two additional elements: a magnification changer and an illuminator which beams the light in through the objective lens. This type of illumination is desirable because the line of illumination is very close to the viewer's line of vision. Therefore, the surgical field
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will be illuminated and free of shadows. Shadows would result if the line of illumination was at a large angle of incidence from the viewing axis.

Common terminology with respect to laboratory, dissection, and surgical microscopes should be understood since these factors have a great deal to do with determining the needs of a specific surgeon for his operation microscope.

![Microscope Basics Diagram](image-url)

**Figure 4. Microscope Basics**
4. Working Distance

*Figure 1-5*, line C is the distance from the microscope objective lens to the point of focus of the optical system and this value is fixed and dependent totally on the chosen focal length of the objective lens. A 250 mm objective lens creates, on a microscope, a 250 mm working area and the criteria for choosing the proper working distance lens depends upon the type of surgery involved. Deep cavity surgeries, such as neuro or laryngeal surgery, require space for both hands to work under the microscope and also must have additional focal length to reach down into the surgical cavity. This is why neurosurgeons almost always use a 300 mm objective lens. It gives them 175 mm to 200 mm of working area under the scope, plus another 100 mm to 125 mm to focus below the skull surface into the surgical cavity.

Laryngeal procedures usually require a 400 mm objective lens so there will be plenty of working area in front of the microscope and still put the point of microscope focus deep into the throat. Ophthalmic surgeons had, in the past, favored the 50 mm objective lens for their anterior segment surgeries.
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However, the eye surgeries of today routinely involve the use of instruments in the posterior eye chamber. 175 mm or 200 mm objective lens focal lengths are now common on ophthalmic microscopes.

5. Eye-to-Object Distance

Figure 5 simply illustrates the distance from the eye of the operator of a microscope to the point of focus of the microscope. The longer the distance, the less likely the surgeon will be comfortable. Modern day surgical microscopes have become large due to all their built-in motorized controls, complicated zoom optics and accessory attachments such as beam splitters and illuminator holding brackets.

6. Coaxial illumination

Microscope illumination can be of two varieties. Originally, microscopes had only externally mounted independent illuminators transmitting light but creating some shadows and unable to get down deep into cavities. The microscope in Figure 6 demonstrates this oblique form of illumination clearly. The need to get the light into the neuro-surgical cavities, through ear specula and down into throats caused the development of the built-in microscope coaxial illuminator. The microscope shown in basic form in Figure 5 contains a coaxial type illuminator. This means that the light from the illuminator bulb is re-routed to a point very near the viewing axis of the microscope and is projected down through the same objective lens used for viewing. In recent years, coaxial illumination has become standard on all ophthalmic microscopes. The developers of the first ophthalmic microscopes incorporated oblique angle forms of illumination to minimize corneal glare from these bright lights. However, the phacoemulsification procedure of cataract removal has led to the requirement for coaxial illumination on eye microscopes. Since microscope coaxial illuminators are several degrees removed from being right on the optical axis, corneal reflection is held to a minimum as are shadows. In the phacoemulsification procedure, the coaxial light shines onto the retina of the patient's eye and illuminates it. The red glow of the illuminated retina, then, acts as a bright backstop for the patient's clouded lens and enables the surgeons to determine that he has emulsified the entire cataract and not any part of it in the eye. Microscope manufacturers provide both types of illumination because oblique and slit illumination can be useful in corneal procedures.

7. Par-Focality

This term refers to the state of optical configuration that enables magnification changes to take place without affecting the point of microscope focus. Since the basic microscope consists of two basic optical components, a binocular and an objective lens, each has its own focal point and focusing properties. Therefore, each operator should undergo a par-focal procedure to customize the microscope optics to their particular eye correction.
7.1. Total Magnification

The focal length of a binocular and the magnifying power of the eyepieces combine to determine the actual power of the total binocular head. However, the actual amount of magnification of the entire microscope head is different from the power of the eyepieces and not always equal to the value printed on the magnification changer knob. The formula for figuring the actual magnification of a total microscope system is as follows:

\[ \text{F.L.} \text{ TUBES} \times (\text{EYEPIECE}) \times (\text{MAG. VALUE}) = \text{TOTAL MAGNIFICATION} \]

This formula is easy to recall since it involves each basic component of the microscope head and the division of the objective lens value into the binocular tube value. This is, likewise, easy to remember because that is their natural configuration on the microscope: binocular above, objective lens below.

7.2. Par-Focus Procedure

A. Position the microscope above a flat, stationary surface.
B. Using a pen or pencil, makes a dot on a piece of white paper to serve as a focus target and place it within the illumination field of the microscope. See Figure 7.
C. Set both of the eyepiece diopter settings to “0”.
D. Set the microscope on its highest magnification setting and focus using the fine-focus control (on the footswitch) until a sharp image is obtained.
E. Being careful not to physically shift the microscope position, change the magnification setting to its lowest position. Focus left and right eyepieces, one at a time, by turning the diopter ring until the image is clear and sharp. Tighten the diopter lock button to lock in this position, and record the settings for future use.
F. Each operator will have his/her particular settings which are to be dialed in whenever that particular operator uses the microscope.
G. This procedure does not have to be repeated by the same operator each time the microscope is used, but rather the diopter settings noted the first time the par-focal procedure was performed by that operator should be used. However, due to changes in eye correction associated with time, it is recommended that this procedure be repeated by the operator once or twice per year.

8. Depth-of-Field / Depth-of-Focus

These terms relate to the area in front of, and behind, the point of perfect optical focus, where sharp focus is maintained. Depth-of-field relates to the latitude or marginal area of sharp focus either side of the object being viewed (or photographed). Depth-of-focus relates to this latitude with respect to the surface upon which the image is reflected, i.e., the retina of the eye or a piece of film. These two values go hand-in-hand and are best explained by using the photographic example. If you take a picture of an object which is exactly 15 feet away from the camera lens, and you focus the camera at 15 feet, there will be a marginal area on either side of that distance which will also fall into perfect focus in the finished picture. In other words, objects at distances ranging from, say, 12 feet to 20 feet in distance may fall into sharp focus in the finished picture objects closer than 12 feet and more distant than 20 feet will be out of focus.

This margin of focus latitude also exists in the instance of viewing objects through optical items such as telescopes, field glasses, etc. In these optical instances, the depth-of-field depends on many factors, the most influential of which are:
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1. Quality of the optical design.
2. Size of the objective lens aperture relative to the focal length of the object.
3. Magnification of the object - the higher the magnification, the more shallow the marginal area of sharp focus and vice-versa.

9. Resolution

This optical term, simply stated, is the quality of a lens (prism or mirror) which enables it to deliver a perfectly crisp image where intended. Resolution and depth-of-field are reciprocals of one another in that more resolution implies less depth-of-field in any one optical design. Optical designers can induce spherical aberration" into a lens formula which will then give greater depth-of-field but less resolving power at any specific focal point. Surgical microscope objects are usually designed to strike a compromise between these two important factors. Manual dexterity under the microscope is aided greater depth-of-field, but high resolution is also needed to prevent ocular fatigue on the part of the surgeon who may work at the microscope for hours on end.

10. Distortion

As optical systems consist of the refraction and reflection of light rays, distortion of the shape and/or color of an image can occur. In the surgical microscope application, color is infinitely more important since the surgeon may discern one anatomical structure from another by its color. However, geometric distortion is readily demonstrated in some microscopes. Observing a perfectly square image under the microscope with geometric distortion produces a non-square image to the viewer.
11. Magnification Changer
A magnification changer is simply a method for varying the magnification of a basic optical system. It may consist of one or several supplemental lens elements which are moved in and out of the viewing axis, or it may be a system of shifting lens elements which change their positions relative to one another such as in a zoom magnification system. Just as the zoom lens of a movie camera changes its focal length variable to create the wide angle (demagnification) and telephoto (magnification increase) images on film, so do the sliding or change optical components in the magnification changers of binoculars, telescopes and microscopes. See Figure 8.

![Figure 8. Magnification Changer Components](image)

12. Virtual Beamsplitter
A beam splitter, as a component of a microscope, is a device with prisms or two-way mirrors which split the optical image into several directions. Since the image is carried by light just as a radio broadcast is carried on a “wavelength” signal, splitting the image infers splitting up the light also. In Figure 9, we see a basic stereo microscope configuration consisting of a binocular head and a close-up objective lens with two additional components added: a beam splitter and a magnification changer. As illustrated, the quality of light is divided by prisms of the beam splitter although the image is diverted at a right angle and also passed through the beam splitter. In order for photographic or observer systems to see down through the microscope, they require a beam splitter to merge their view path in with that of the surgeon. The decrease of light transmitted to the surgeon's eyes is usually not a problem since the human eye is quite versatile in its ability to adjust to lower light levels. However, photographic systems, particularly TV cameras, are not very versatile in this respect, and for this reason some beam splitters are designed to divert a greater share of light to the accessory ports and pass less light to the surgeon's binocular.
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Figure 9. Using a Virtual Beamsplitter