Ergonomic considerations in the design of neurosurgery instruments

GERMAN NÚNEZ, PH.D., AND HOWARD KAUFMAN, M.D.

Departments of Industrial Engineering and Neurosurgery, West Virginia University, Morgantown, West Virginia

✓ Surgical instruments should be designed to optimize control and interact with tissues or other objects while avoiding surgeon fatigue, muscle spasms, tissue ischemia, and injuries. Several well-established ergonomic criteria can be used in the design of instruments. Analysis of some commonly used bone biting instruments reveal how they violate these criteria. The thoughtful redesign of instruments using these principles is recommended.

KEY WORDS • instrumentation • ergonomics

OPTIMIZING the performance of surgery depends on a surgeon developing the appropriate skills and employing tools designed to best accomplish his needs. As mentioned previously, surgical tasks have not been systematically studied, and have therefore not been methodically taught. Similarly, surgical tools have not always been designed from the ergonomics viewpoint. Some instruments in current use are not optimal in terms of their active or biting ends and linkages, and many are not even designed to fit in the surgeon’s hands. Such inappropriately designed instruments may not carry out their functions optimally, and their prolonged use may cause the surgeon unnecessary fatigue, muscle spasms, tissue ischemia, and even bone deformities.

We propose that surgical instruments should be designed using ergonomic principles. This paper describes these principles, points out how they are used in designing hand tools in industry, and illustrates the deficits in the design of current neurosurgical instruments.

Design Criteria for Neurosurgical Instruments

For hand-held instruments used in neurosurgery, ergonomic design criteria should aim to provide the optimal interaction between the surgeon’s hand and the tool. There should be provision for easy control of gross and fine movement, for maximal generation of power, and for comfort. Prolonged use should not cause fatigue. In order to insure the stated attributes, ergonomic design criteria should include the following specifications, but not be limited to them.

Tendon and Ligament Stress

Use of the instrument should not cause ulnar deviation, radial deviation, palmar flexion, or dorsiflexion. Failure to maintain the wrist straight will cause the flexor and extensor tendons to bend and to become subject to mechanical stress which will traumatize the tendon sheaths and ligaments. Ulnar deviation combined with supination can cause tenosynovitis, while radial deviation, particularly when combined with pronation, can induce epicondylitis or epicondylar bursitis. In a study comparing two groups of trainees in electronic assembly, Tichauer showed that, in workers using straight pliers that produced ulnar deviation, “a gradual increase in the disease is observed.” In general, the above-mentioned deviations of the wrist can also cause compression of blood vessels, nerves, and tendons of the hand, especially those that pass through the carpal tunnel, as well as the ulnar nerve and the ulnar artery. It has also been observed that, if the forearm flexor muscles are in the extended or flexed position, grasp force will be reduced by 30%, even with an optimally sized instrument.

Figure 1 shows x-ray films of hands holding a commonly used bone punch and a rongeur. The ulnar deviation is obvious.

Spinal Deviation

Use of the instrument should not produce a “boot-welder” position. This commonly observed position results when one of the surgeon’s shoulders is raised higher than the other, with resulting spinal deviation.
Ergonomics in surgical instrument design

Fig. 1. X-ray films of hands holding a bone punch and a rongeur. A and B: The hand of a woman holding a bone punch in the open and closed positions, respectively. Note that in both cases there is significant ulnar deviation (approximately 50°). C and D: The hand of a man holding a double-action ronguer in the open and closed positions, respectively. The ulnar deviation (approximately 50°) is evident in both cases.

In many instances this position is induced by the use of an improperly designed instrument. Figure 2 depicts a surgeon operating in the boot-welder position. Functional scoliosis will persist in the exact posture for some time after the work is performed.

Linear Grip Span

The linear grip span of an instrument is the distance between the furthest hand-tool contact points in each of the handles of the instrument. In order to accommodate the hand anthropometry of 95% of the male and female population (a generally accepted criterion for tool design, see below), the linear grip span of instruments held in one hand should not exceed 4½ in. from one contact point to the other; however, it should not be less than 3½ in. (see below). Figure 3 shows the linear grip span in several commonly used surgical instruments.

Maximum Grip Force

The maximum grip force is the maximum cutting or biting force that can be generated or obtained with an instrument held in one hand. The actual bite, from point of contact to finish, is most effective when the

Fig. 2. Drawings of a surgeon assuming the “boot-welder” position while operating. This position is commonly observed in neurosurgeons operating on patients. Functional scoliosis may persist from a few minutes to hours after the surgical procedure.
FIG. 3. Linear grip span of commonly used instruments in neurosurgery shown against an inch measure. The bone punch and the ronguer shown in A and B have a linear span of 3½ in. while the ronguer in C has 3¾ in. of span between the handle contact points.

The hand's linear grip span is between 3 and 3½ in. Fitzhugh studied the maximum grip forces generated by males and females. He concluded that for both males and females, these forces were generated when the linear grip span was between 3 and 3½ in., although the maximum grip force generated varied significantly among these two groups. Figure 4 summarizes the results obtained by Fitzhugh. It is obvious that, with an instrument such as the ronguer shown in Fig. 3B which has a linear grip span shorter than 3½ in., it would not be possible to generate maximum grip/cutting forces. Figure 5 shows the linear span at biting distance of the three instruments shown in Fig. 3.

**Point Pressure**

Point pressure around the palmar tissue and handles can occur with instruments more than 4 inches in length and/or with ¼ in. of curvature. Whenever possible, a handle of about ½ in. in radius should be used. Contact surfaces between the hand and the surgical instrument should be designed to avoid concentration of high compressive forces and stress. Compromise of circulation or nerve compression can cause early fatigue and/or numbness and tingling of the fingers and reduce accuracy and dexterity. Greenberg and Chaffin recommend that "the cross section configuration of a handle to be squeezed...should distribute forces and allow fingers to wrap around the handle." An oval shape is recommended because it may reduce compression of the surgeon's tendons, tendon sheaths, arteries, nerves, and veins, which may cause discomfort immediately and tendon irritability in the long run.

**Finger Recesses**

Since finger and hand anthropometry may vary greatly within the population, instruments should be provided with finger recesses only when the primary force is pulling across the palm and/or when small forces (no greater than 15 lbs) are expected. In any event, recesses greater than ¼ in. deep are discouraged. Figure 6 shows the effect of misplacement of recesses on a bone punch.

**Skin-Pinching**

The joints and unions of the instrument should not
Ergonomics in surgical instrument design

Fig. 5. Left: Linear grip span of a bone punch in its "biting" position. The linear span in this case is less than 2 in. Forces generated at this grip span are also minimal. In order for the instrument to be efficient, the "biting" should occur at a span of at least 3 in. Center: Linear grip span of a ronguer in its "biting" position. According to Fig. 4, at a linear span of 2 in., minimal forces of only 10 to 40 lb are generated. Right: Linear grip span of a double-action ronguer. The linear grip span in the "biting" position is about 3 in., where maximum grip forces are generated.

be placed where either the skin of the surgeon or the skin of the patient could be caught accidentally. Handles should be separated by at least 1 in. when the jaws are closed, and the area of junction of tool handles should be rounded to reduce pinch hazard.6

Angle of the Handle

The "Bennett handle" was originally introduced in the 1970's and utilizes a 19° double-ellipse, following approximately the same angle as formed by the index finger and the life line under the thumb. Its creator noted that, when the hand is closed, an ellipse is formed.

Fig. 6. Negative effect of finger recesses. Left: The recess in the bone punch shown, rather than aiding the grip, becomes a protruding object and a source of discomfort to the surgeon's hand. Extended use of the bone punch in this position will cause a bruise in the thenar eminence and will reduce circulation to the index finger. Right: The front finger recess in the bone punch shown becomes an obstructing element and a source of discomfort to the operating surgeon. This instrument was obviously designed taking into consideration right-handed people only; hence the importance for standardized design for use with either hand.
by the bottom of the hand and the knuckles of the closed fingers. In industrial operation, the handle has been successfully used in brooms, hammers, and pliers. It is important to note that using the “Bennett handle” concept, our group at West Virginia University has developed a prototype rongeur which does not cause radial deviation while in use.

Grip Force

The maximum grip strength generated by 95% of the female population is 60 lbs (Fig. 4). Surgical instruments should be designed to operate adequately at this force, which would also accommodate 99.9% of the male population. Conversely, the surgeon’s strength might be tested and if it is inadequate, it can be increased by training or mechanical linkages might be added to the instrument to aid in the amplification of forces.

Weight and Size of Instrument

The weight of an instrument should be proportionally distributed and balanced. In the vast literature reviewed by the authors, there was no evidence that studies had been carried out in the past to determine the optimum weight of an instrument or the effects of weight and weight balance and distribution on the control of fine and gross movement. This is an important area that needs research. Another criterion of importance is the weight of an instrument. The weight should not, by itself, cause the surgeon fatigue. Again, this area requires further research.

The size of an instrument should be appropriate for 90% of the surgeon population. It is a good design practice to try to accommodate the characteristics and the potential user population within the 5th and the 95th percentiles. Although females currently only represent about 7% of neurosurgeons and about 28% of the total surgeons in training,2 surgical instruments should be designed taking into consideration female anthropomorphics and anthropometry. When the instrument is expected to have a significant market in foreign countries, the physical characteristics of the foreign users must also be considered for the design.

Use by Either Hand

Instruments should be designed in such a fashion that they can be utilized by both left-handed and right-handed people with no compromise of performance. Figure 6 shows a bone punch obviously designed for use by right-handed surgeons only.

Surface and Texture of Instruments

Matte surfaces are preferred to bright, highly polished surfaces. The reflection of surgical lights may cause vision fatigue to the surgeon and/or the staff. The surface reflection of surgical instruments as a function of the intensity of the lights in the normal operating room and their influence on vision fatigue of the individuals who work in operating rooms represent an area that needs further research and attention.

Because they are slippery, smooth surfaces are only recommended when small forces are needed to operate the instrument. Texture is helpful to minimize slippage. However, it is recommended that coarse texture be provided only in the form of granulation or “sandblast” finish (a slightly rough finished surface) around the areas where the hand or fingers come into contact with the instrument. Surfaces must also be “compatible” with the rubber material used in surgical gloves. This means that the surface and texture of the instrument must not rip, cut, abrade, or chemically react with the glove material.

Color-Coding

Color-coding will help in identifying the instruments on the operating table, allowing for faster, more reliable discrimination between the various instruments. When an instrument is produced in various sizes, a color-coded means of size discrimination is recommended, such as color-coded handles or color-coded rings around the handles. However, the use of green, red, and yellow is discouraged since they are generally utilized to imply safe, danger, and warning, respectively.

Functioning End

The active or biting end of the instrument (the part of the instrument that comes into contact with tissue or is used for positioning material) must also be designed to optimize performance. There are a variety of functions that instruments perform, including holding tissue (either transiently or in a locked position), blunt dissection, sharp dissection (knife and scissors), biting, positioning materials (such as patties or bone wax) or other instruments (such as aneurysm clips), and cauterizing. A number of aspects relating to the ends must be kept in mind, including the angular orientation of the end in relation to the axis of the shaft, the size and shape of the active end, and the sharpness and texture of the working surfaces. Where there are two jaws or blades that oppose, the effectiveness of the mechanisms and guides to align these components as well as the smoothness of their actions are essential. Of course, the strength of the ends and their durability in terms of maintaining textures and edges are also important.

Conclusions and Recommendations

Ergonomic criteria have been described and should be used to guide in the optimal design of surgical instruments to be held in one hand. These criteria are used extensively in industry. However, numerous discussions with companies manufacturing instruments and with neurosurgeons designing their own instrument lines have revealed that many are not aware of the principles. An evaluation of widely used neurosurgical instruments has revealed that they indeed violate these
Ergonomics in surgical instrument design

criteria. This article is intended to elucidate ergonomic principles and the need for improved instrument designs as well as making neurosurgeons aware of these criteria so they can make a better selection when purchasing instruments.

References

5. Garrett JW: Anthropometry of the hand of male air force flight personnel. AMRL-TR-69-42. Fairborn, Ohio: Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, 1970

Manuscript received November 18, 1987. Accepted in final form February 29, 1988. Address reprint requests to: German Nuñez, Ph.D., Department of Industrial Engineering, Florida International University, Miami, Florida 33199.