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The Design and Evaluation of the Neutral Posture Chair for Surgeons

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A neutral posture chair was designed and evaluated to determine if it was a possible means for reducing or eliminating fatigue experienced by surgeons because of seated body posture during microsurgical procedures. The neutral body posture is defined as the posture found in weightlessness, where the muscle, tendon, and ligament systems acting over the joints are in total balance. The neutral posture chair is a unique combination of a forward-sloping cultivator seat and an English saddle, with wraparound leg trough support. On subjective questionnaires, surgeons rated the neutral posture chair as being generally superior to a currently utilized surgical chair for general comfort, body-part comfort, and chair features.

INTRODUCTION

It was the purpose of this paper to find a means of reducing or eliminating fatigue experienced by the surgeon because of seated body posture during microsurgical procedures.

Microsurgery is operative surgery using magnification. The surgeon sits because he or she needs stability, steadiness, and precision. He or she may be seated for as little as 15 min or for more than 6 h during these stressful and fatiguing activities.

The objectives of this paper are to state surgical chair design guidelines, describe a prototype surgical chair based on the neutral body posture, and report the results of the evaluation of the newly designed prototype neutral body posture surgical chair as contrasted with a commercially available surgical chair, the Stryker SurgiStool. Subjective surveys and questionnaires were used to contrast the two chairs.

Currently, the only researcher to offer any practical alternative posture for sitting has been Mandal (1981, 1982). Mandal (1981, 1982) using the work of Keegan (1953), through a series of tracings from X rays of the lumbosacral spine, pelvis, and femur of subjects, determined that the normal curve of the lumbar spine in an adult male is determined by maintenance of trunk-thigh and knee angles at approximately 135 deg. Mandal (1981, 1982) employed a tilted seat pan and a higher work surface to approximate the 135-deg angle between the trunk and the thigh.

Mandal (1982) concluded that a more upright posture allows for better breathing, reduces swelling of the ankles, enhances the ability to move legs more freely, and allows a greater ease in rising from the seat pan because the posture is a compromise between

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standing and sitting. With regard to the increased load experienced by the legs in countering the ejection force of the tilted seat pan, Mandal (1982) never found more than about 35% of the body weight located at the feet.

In order to define and evaluate the current problems in seated microsurgery, data were gathered about chairs currently being utilized in microsurgery activities. Various postures of surgeons were observed and photographed while the surgeons performed seated tasks, and a survey was conducted with surgeons who perform microscopic surgery while seated.

Color slides, black and white prints, and 16-mm film of actual microscopic surgical procedures were taken in the present study to assist in analyzing the surgical workplace layout and to document the postures utilized by the surgeons. A representative posture of a surgeon performing a microscopic surgery and the Stryker SurgiStool are shown in Figure 1.

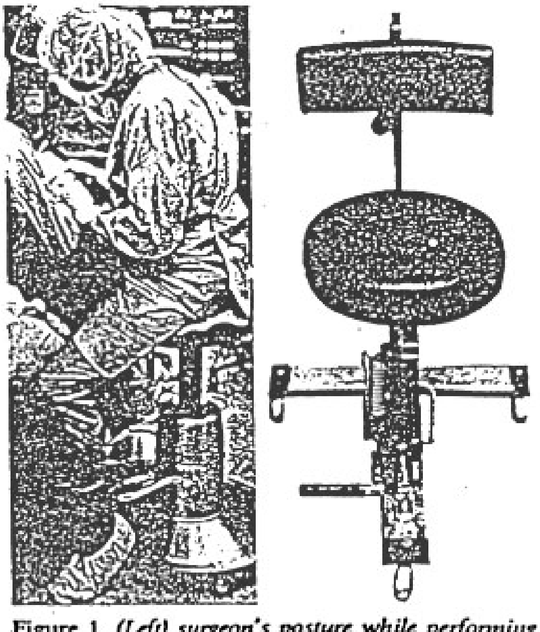

Figure 1. *(Left) surgeon's posture while performing microsurgery; (right) Stryker Surgistool.*

After numerous studies of microsurgical operations, the following observations regarding the posture of the surgeons were noted:

(1) The surgeon assumes more of a sit-stand posture and sits on the front edge of the seat pan, primarily because the diameter of the seat pan allows only minor trunk-thigh angle variation.
(2) The surgeon very seldom uses the backrest because he or she sits on the front edge of seat pan and also because some chairs do not provide the backrest.
(3) The surgeon's abdomen is usually placed against the table or table extensions.
(4) The surgeon either places his or her elbows on the table or table extensions, or does not utilize any support.
(5) The surgeon places the wrists on wrist rests or on the patient.
(6) The surgeon utilizes all available foot room area and very frequently changes the position of the lower leg and feet.

The seated posture recommended by Mandal (1982) closely approximates the seated posture of microsurgeons observed. It was suggested that an incorporation of a saddle might help to resolve the problems of the ejection force caused by the tilted seat pan. Therefore, a pilot study of subjects seated in an English saddle while performing a typing task was initiated and conducted.

Evaluation of the incorporation of the English saddle concept from the pilot study yielded the following conclusions (Congleton, 1982):

(1) The English saddle proved to be too wide, which forced the legs laterally, thus causing fatigue.
(2) Significant pressure on the ischial tuberosities was reported by the two subjects, and eight layers of foam rubber had to be placed on the saddle before the 30-minute task could be completed.
(3) No forward ejection force was noted when using the English saddle, regardless of the trunk-thigh angle.

Because an acceptable chair did not appear to be available, it was decided to design and develop a new chair for microsurgery.

Design of Seats—New Guidelines

In the process of designing a new chair, a review of literature for the design of previous chairs was conducted. The recommended approach to designing a workplace for the seated individual is to take the individual into account in the initial stages of design by considering the person's anthropometric, biomechanical, physiological, and anatomical properties because doing so will reduce fatigue, improve efficiency, and enhance performance (Ayoub, 1971). A good chair should permit changing of posture (Ayoub, 1971) because changing postures facilitates blood flow and venous return, two factors that help to prevent fatigue (Astrand and Rodahl, 1977).

Important areas of consideration in establishing surgical chair design guidelines are stability, mobility, backrest, armrests, footrests, conductive casters, cleaning, cushioning material, and seat pan design.

The chair must be stable yet mobile. Stability is essential for steadiness. The seat pan must be stable to permit shifts in posture, and the base should resist tipping over. Mobility is essential to provide access to the best posture for the surgical task to be accomplished. Conductive casters are necessary because all equipment contained in the operating theater is required to be conductive in order to prevent build-up of static electricity.

The gloved hands of the surgeon must remain sterile during the operation; they therefore cannot adjust the controls unless the adjustment knobs are covered by sterile bags. Also, the chair should be designed so that the surgeon need not vacate it when reaching for these adjustment-control knobs. Frequently used controls on the chair that should be foot operated include height of seat pan, tilt of seat pan, and horizontal backrest adjustment. Backrest adjustments for vertical and horizontal alignment need not be foot operated because they are adjusted infrequently.

Armrests should not be included on the chair because armrests are seldom used and they are very difficult to cover and keep sterile. Armrests should be attached to the operating table, where the normal sterile coverings can be used. The chair itself should have footrests so as to allow frequent and unencumbered posture changes for the feet. From conversation with the surgeons, there was unanimous agreement that footrests should be included. They should be adjustable in tilt (0-15 deg) to allow varied foot and ankle posture and to accommodate any foot controls (microscope, cauterizer, etc.) that are placed on the footrests.

Although the frame, seat pan, and backrest need not be sterile, construction and material should allow for easy cleaning to inhibit the growth of bacteria. The cushioning material for the seat pan should be medium foam as recommended by Reddy (1982), who used a simplified two-dimensional model of the buttock, 13.9 cm in diameter, to test five cushion materials for maximum compressive stress and maximum shear stress. For maximum compressive stress, the cushion materials were ranked from least to highest stress: (1) medium foam, (2) soft foam, (3) PVC gel, (4) viscoelastic T-foam, and (5) stiff foam (Reddy, 1982). For maximum shear stress, the cushion materials were ranked lowest to highest: (1) medium foam, (2) soft foam, (3) viscoelastic T-foam, (4) stiff foam, and (5) PVC gel (Reddy, 1982). Reddy (1982) also noted that "doubling the thickness of foam cushions from 3.8 cm to 7.6 cm considerably decreased the high stress regimes" (p. 503). It may well be that the gel and viscous fluid pads will distribute the pressure better than will a medium foam-rubber pad above 1.0 psi. However, because the buttock pressures generally found with cushioned materials are generally low (0-1.28

psi), as determined by Rebiffe (1969) and by Lay and Fisher (1940); for people with normal fascia (fat) and muscle development, foam became the obvious choice.

The seat pan design should allow maintenance of various trunk-thigh angles while countering the ejection force with the incorporation of a saddle concept in order to allow the surgeons to assume their normal posture without experiencing physiological stresses. The seat pan height should be adjustable because of individual anthropometric differences and the variable postures the surgeon may want to attain. The seat pan tilt should be adjustable (trunk-thigh angle of 90-140 deg) because the changing of posture promotes blood distribution and allows the individual to attain the best trunk-thigh angle. The seat pan design should provide additional surface area and support so as to decrease pressure on the ischial tuberosities and ensure good blood distribution in the buttocks and lower extremities.

Determining Neutral Body Posture

Is there a posture that places the skeletal and muscle systems in balance? It appears that the neutral body posture accomplishes this task.

The neutral body posture is defined as the posture found in weightlessness, where the muscle, tendon, and ligament systems acting over the joints are in total balance. The neutral body posture concept for seated microscopic surgery was selected for the following reasons:

(1) Microsurgeons almost always assume a neutral posture in the performance of the highly skilled task of microsurgery, irrespective of the interface with the table or table attachments.
(2) A highly promising reduction of stresses on the total body posture would occur if the neutral body posture found in weightlessness could be used in a 1-G environment by providing a seat pan and other required support.

NASA (1978) has provided the following description of the posture in weightlessness (see Figure 2):

(1) The relaxed, unrestrained human body automatically assumes and indefinitely maintains a single characteristic posture with relatively minimal variations in angular relationships.
(2) Attempts to maintain postures away from this neutral posture either by the subject or through external constraint frequently leads to discomfort, fatigue, and inefficiency.
(3) Plantar flexion of the feet occurs.
(4) Flexion of hips and knees appears to be in mid-range of joint flexibility with slight abduction of the legs.
(5) The thoraco-lumbar spine flattens or becomes slightly flexed anteriorly (lordosis).
(6) The cervical spine (neck) straightens and angles anteriorly.
(7) The head becomes slightly inferior and anterior, thus lowering the normal angle of vision.
(8) Shoulders become elevated.
(9) Upper arms become abducted and elevated and have marked anterior positioning.
(10) Elbow flexion is moderate (about mid-range).

NASA has developed a variety of data concerning neutral posture which includes zero-G and water immersion studies. From the information provided, it was theorized that the zero-G posture could be predicted through flexibility measurements (for example, flexion-extension). This theory states the midpoint of the bisection of the angle found by full voluntary flexion to full voluntary extension would yield the zero-G posture angular relationships.

The midpoint of the joint range of motion of the limbs proved to be a reasonably good predictor of the angular relationships displayed by body in a weightless environment. For this reason, the angular relationships of segment lengths and their source, the midpoint range of motion, and the Griffin (1978) NASA data for postural angles in weightlessness and are presented in Table 1.

EVALUATION METHODS

The General Comfort subjective surveys developed by Shackel, Childsey, and Shipley

(1969) were used extensively for contrasting chairs and posture treatments.

The Body Part Discomfort subjective form developed by Corlett and Bishop (1976) and used by Drury and Coury (1982) was modified for our use. It was felt that this new, modified Body Part Discomfort Form would provide finer discrimination than that obtained by having subjects choose a number between one and five and placing that number on the pictured body part in discomfort. Instead, the subject placed an *X* on the line corresponding to the body part in discomfort. The lines were 10 cm long, and the position of the subject's *X* was measured from the left-hand end of the scale, which was given a value of 1. If no mark was made on the scale for that body part, a zero value was recorded, indicating no no-

TABLE 1

Comparison of Midpoint Range of Motion to Weightlessness Postural Angles

Angular Relationships of Segment Lengths	*Source*	*Midpoint of Range Motion*	*Griffin (1978) NASA Data—Weightlessness*
		(deg)	(deg)
Shoulder abduction	Barter (1957)	43	39 ± 11
Shoulder flexion	Barter (1957)	45.5	36 ± 19
Elbow flexion	Barter (1957)	106	122 ± 24
Hip flexion	Leighton (1942)	127	128 ± 7
	Barter (1957)		
	Sinelkinoff (1931)		
	Heck (1965)		
Knee flexion	Leighton (1942)	127	133 ± 8
	Barter (1957)		
	Heck (1965)		
Ankle flexion	Heck (1965)	15	21 ± 7

ticeable pain or discomfort. The use of this methodology in the modified form permitted statistical analyses to test for significant differences between chair posture treatments for body part discomfort.

The Chair Feature Checklist subjective form developed by Shackel et al., 1969, and modified by Drury and Coury (1982) was modified further for use in this study. Subjects were instructed to mark an *X* at the point on the line that corresponded to their opinion of the chair feature, as this was felt to be a more accurate representation than encircling the line at that point. Changes were also made in the description of each chair feature in an attempt to establish clearer end points for the scale, better descriptions, and more consistency. On scales in which "correct" was not the center portion, these chair features were placed in blocks to allow subjects to discriminate between the scale designs. Subjects were also instructed that the chair feature scales with blocks were designed with *worst* being on the left and *best* being on the right. For scales with "correct" at the center, measurements (cm) were made and recorded from the center point, (−) to the left and (+) to the right. For scales in which *worst* was on the left and *best* on the right, measurements (cm) were made and recorded, measuring from the extreme left portion of the scale.

Subjects

Subjects were recruited from the population of surgeons in the Lubbock, Texas, area who used a chair while performing surgery. Thirteen male surgeons were selected based on availability. Males were selected because the surgeon population is predominantly male, and the seat pan on the prototype chair was designed for males. Members of the group ranged in age from 28 to 59 years. They were between 170 and 188 cm tall and weighed between 63 and 91 kg.

Experimental Procedure

The neutral posture chair is depicted in Figure 3, which shows the chair and the recommended workplace neutral posture as well as the surgeon sitting in the chair while performing surgery during the evaluation. The surgeon and the experimenter adjusted the chair for the most adequate interface with patient, table, and/or microscope. It was not possible to measure the exact trunk-thigh posture angle during surgery because doing so would have required contaminating the sterile environment. However, by experimenter evaluation, the trunk-thigh posture was approximately 127 deg. This figure was verified subsequently through photographs.

Each surgeon completed a subjective survey after each actual surgical procedure. (The surgeon could not mark the scale personally during the surgery while maintaining the sterile conditions.) In general, each surgical procedure lasted between 45 and 60 minutes. The surgeon subjects completed subjective surveys that corresponded to 30-minute intervals for the entire 2.5 h of actual surgery time. Thirteen surgeons participated in the actual surgery evaluation, with each surgeon performing two random treatments with no replications. The random treatments were utilization of the neutral posture surgical chair and the Stryker SurgiStool at the approximately 127-deg trunk thigh posture for 2.5 h each.

RESULTS

User Comfort Evaluation

The results of the Surgeon General Comfort Survey are depicted in Figure 4, along with the means ± one standard deviation and the results of the testing for significant difference at $F(1,21) = 4.32$, $p < 0.05$.

The results of the analysis of variance for general comfort for the first through the fifth

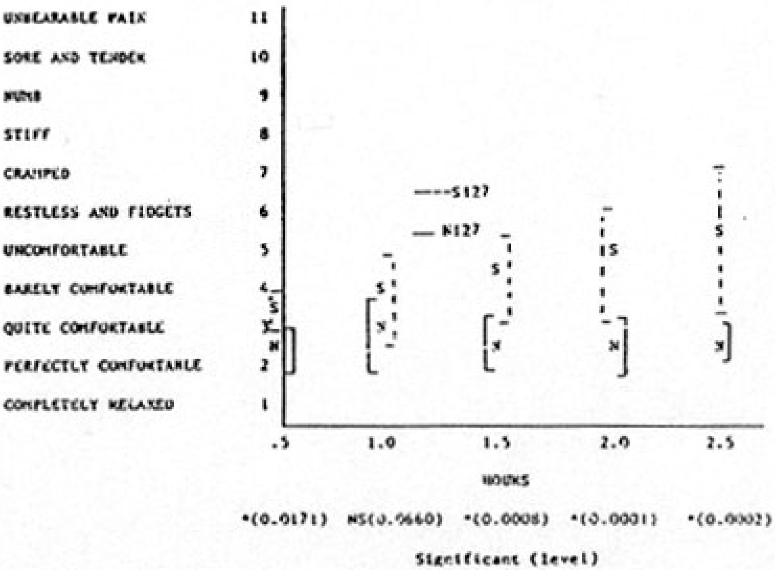

Figure 4. *Surgeon General Comfort—mean + one standard deviation and significance level for neutral posture chair (N) and Stryker chair (S).*

half hour showed significant differences between all treatments except for the second half hour. The neutral posture chair, 127-deg posture, received a relatively constant general comfort rating between perfectly comfortable and quite comfortable as opposed to the Stryker chair, 127-deg posture, general comfort rating of just barely over quite

TABLE 2

Surgeon Body Part Discomfort at 0.5-h Intervals for 2.5-h Clinical Evaluation

	0.5 h		1-h		1.5 h		2 h		2.5 h	
	N	S	N	S	N	S	N	S	N	S
Neck	0	0.10	0	0.31	0	0.42	0	1.20	0	1.30
Shoulders	0	0.35	0	0.40	0	0.33	0	0.40	0*	1.30*
Upper back	0	0.52	0*	0.79*	0*	0.94*	0	1.40	0.30*	2.60*
Upper arm	0	0	0	0	0	0	0	0	0	0
Mid back	0	0.13	0	0.30	0.11	0.66	0.10	0.49	0.17*	0.90*
Lower arm	0	0	0	0	0	0	0	0	0	0
Lower back	0.34	1.10	0.24	1.30	0.39*	2.40*	0.38	1.80	0.27*	2.40*
Buttocks	1.70	1.90	1.90	2.20	1.70	3.00	0.95*	3.40*	0.80*	3.60*
Hand	0	0	0	0	0	0	0	0	0	0
Thighs	0.42	0.67	0	0.90	0	1.10	0	1.10	0	1.1
Legs	0	0.64	0*	1.40*	0*	1.60*	0*	1.60*	0*	1.60*

0—no pain/discomfort
1.0—Just noticeable pain/discomfort
5.55—Moderate pain/discomfort
10.10—Intolerable pain/discomfort
*—Significant difference between treatments $p < 0.05$
N—Neutral posture chair, 127 deg
S—Stryker chair, 127 deg

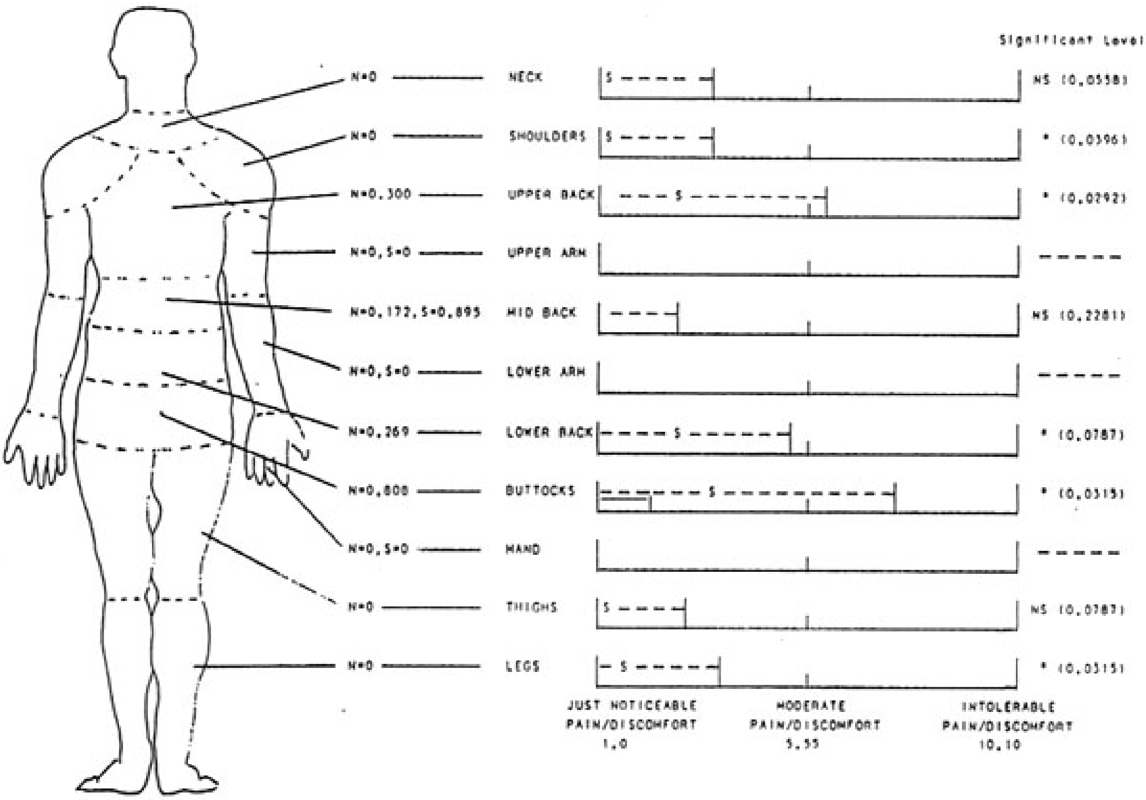

Figure 5. *Surgeon Body Part Discomfort—mean + one standard deviation and significance level at the completion of 2.5 h of evaluation for neutral posture chair (N) and Stryker chair (S).*

comfortable to between uncomfortable and restless and fidgety at the end of the fifth half hour.

Body Part Discomfort

The results of the Surgeon Body Part Discomfort Survey at 0.5-h intervals for the 2.5-h clinical evaluation are shown in Table 2. The results for the Surgeon Body Part Discomfort Survey and testing for significant differences at the $F(1,21) = 4.32$, $p < 0.05$ level at the completion of 2.5 h of evaluation are depicted in Figure 5.

The significant differences between the neutral posture chair, 127-deg posture and the Stryker chair, 127-deg posture were always in the direction of the Stryker chair, 127-deg posture as producing significantly more discomfort. Increased discomfort for the shoulders, upper back, and lower back for the Stryker chair, 127-deg posture was probably due to the fact that in some cases the backrest could not be used and was therefore of no assistance in providing support to the lumbar area of the spine, which provides stability and support for the trunk. We reasoned that buttock discomfort was probably due to the high maximum pressures produced by sitting on the front edge of the Stryker chair; this was later verified by pressure transducer measurement in a separate study as averaging 2.9 psi for the Stryker chair, 127-deg posture, and 1.2 psi for the neutral posture chair, 127-deg posture.

The Stryker chair, 127-deg posture, thigh body-part discomfort was the result of pressure from the front edge of the chair at the gluteal fold (the general area of which includes the ischial tuberosities and sciatic nerve).

Chair Feature Checklist

The modified Chair Feature Checklist survey form developed for this study was relatively easy to use. Of interest was a comparison of the means ± one standard deviation and checking for significant differences (ANOVA) at $F(1,21) = 4.32$, $p < 0.05$, for each chair feature for the neutral posture chair and the Stryker chair at the 127-deg posture for the clinical evaluation by surgeons (see Figure 6).

The neutral posture chair was generally rated superior to the Stryker chair. The small, round seat of the Stryker chair was rated as being short in seat length and narrow in seat width. The neutral posture chair was also rated superior for seat shape and for the molded chair back. The surgeons' initial comments about the footrests on the neutral posture chair were very negative, but upon completion of the 2.5-h test, they were quite complimentary regarding their comfort and the capability of interfacing with foot pedals of auxiliary equipment used during the surgery.

CONCLUSIONS

New chair design guidelines were proposed prior to the development of a prototype chair. After evaluation of the neutral posture chair by surgeons and observations by researchers, the following modifications to these chair design guidelines were made:

(1) The neutral posture chair base needed to be redesigned to provide mobility. Mobility was accomplished by an assistant pushing the surgeon into position. Also, the base was too large and bulky and needed to be streamlined to allow better interface with the surgical table. The front portion of the currently designed base made contact with table control pedals and forced the surgeon to lean forward more than normal and/or to sit more on the pommel area of the seat pan.

(2) The backrest needed to be narrower in order to prevent contamination of the sterile environment by the surgeon's elbow coming into contact with the backrest.

(3) The pommel area of the neutral posture chair needed to be lower. The pommel area tended to catch the surgical gown (which resembles a tight skirt when donned by the surgeon) and prevented the surgeon proper access into the seat pan.

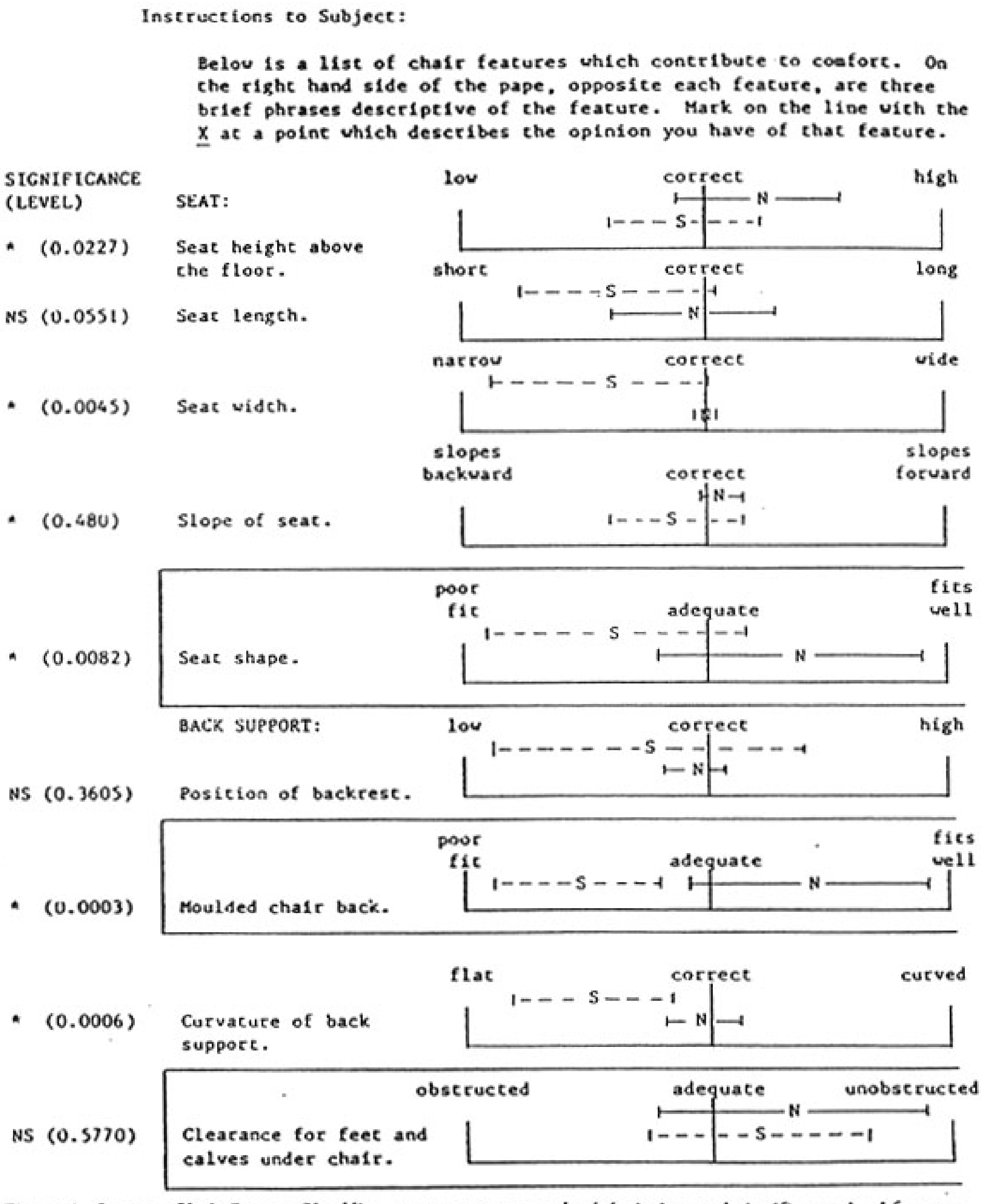

Figure 6. *Surgeon Chair Feature Checklist—mean + one standard deviation and significance level for neutral posture chair (N) and Stryker chair (S).*

(4) The footrests needed to be adjustable in height to provide a range of angles from 0 to 15 deg. This was necessary because of various foot pedals placed on the foot rests. It may also be necessary for the foot rests to slide in order to provide foot access to the floor, thus allowing mobility.

(5) A foot brake needed to be installed on the base to allow the surgeon to get into and out of the chair safely. Because the surgeon's hands must remain sterile, they should not be used in accessing the chair seat pan.

The subjective surveys employed in this study were easy to use. The chair feature checklist, which had been modified to provide slightly varied, more descriptive phrases as well as to allow subjects to mark the line with an *X* rather than a circle, proved to be a more accurate means for measurement. The modified body-part discomfort survey form developed for this study allowed statistical comparison of the data for body-part discomfort which previously had not been possible.

The results of this study indicate that a less fatiguing and more comfortable posture was obtained by surgeons using a neutral posture chair as compared with the traditional Stryker Surgistool. The neutral posture chair in the 1-G environment did support the muscle system in a nonstressed posture. It was also evident from this study that a backrest is necessary to provide lumbar support.

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