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SURGICAL ENDOSCOPY
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A newly designed ergonomic body support for surgeons

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Abstract
Background: One of the main ergonomic problems during surgical procedures is the surgeon's awkward body posture, often accompanied by repetitive movements of the upper extremities, increased muscle activity, and prolonged static head and back postures. In addition, surgeons perform surgery so concentrated that they tend to neglect their posture. These observations suggest the advantage of supporting the surgeon's body during surgical procedures. This study aimed to design a body support and to test its potential.
Methods: The optimum working condition for a surgeon is a compromise between the spine and arm positions and the level of effort and fatigue experienced performing a procedure. The design vision of the Med*i*sign group has led to the development of an ergonomic body support for surgeons that is suitable for use during both open and minimally invasive procedures. The feasibility of the newly designed ergonomic body support was assessed during seven surgical procedures. Electromyography (EMG) was performed for back and leg muscles using the body support in an experimental setting.
Results: Six of seven participating surgeons indicated that the body support was comfortable, safe, and simple to use. The EMG results show that supporting the body is effective in reducing muscle activity. The average reduction using chest support was 44% for the erector spinae muscle, 20% for the semitendinosus muscle, and 74% for the gastrocnemius muscle. The average muscle reduction using semistanding support was 5% for the erector spinae, 12% for the semitendinosus muscle, and for 50% for the gastrocnemius muscle.
Conclusion: The results of this study imply that supporting the body is an effective way to reduce muscle activity, which over the long term may reduce physical problems and discomfort. Additionally, the product supports the surgeon in his natural posture during both open and minimally invasive procedures and can easily be adapted to the current layout of the operating theater.

Key words: Body support — Electromyography — Ergonomics — Minimally invasive surgery

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Increasingly, more general surgeons are performing minimally invasive procedures in addition to open surgery. Although the basic laparoscopic and open procedures are comparable, minimally invasive procedures have altered the way surgeons interact with the surgical field, which requires a change in the surgeon's posture. A head- and back-bent posture and a twisted torso characterize the posture of the surgeon during open surgical procedures. Conversely, during laparoscopic procedures, the posture of the surgeon is characterized by a head- and back-straight posture. The poor ergonomic posture of surgeons during both kinds of procedures can result in discomfort.

Due to the position of the patient during open surgery, surgeons tend to lean forward toward or even over the surgical field to see and manipulate the tissue. This leaning forward results in increased muscle activity to balance the upper body. Kant et al. [10] reported that surgeons and scrub nurses exhibited frequent static body postures that were "distinctly harmful" and contributed to physical fatigue during surgery. Maintaining the awkward position of the body for longer periods results in musculoskeletal fatigue and physical complaints on the part of surgeons. After open surgery, 30% of surgeons report pain and stiffness of shoulders, neck, and lower back [12].

During minimally invasive surgery, the upper extremities usually are in uncomfortable excursion for handling the long laparoscopic instruments. The upright posture during these procedures, however, seems to be accompanied by substantially less body movement and weight shifting than during open surgery [6]. Cuschieri [8] has described a "surgical fatigue syndrome" that occurs after minimally invasive surgery has been performed for 4 h.

In addition to poor posture, which can cause musculoskeletal fatigue, the surgical team also has to deal with problems related to nonoptimal working height. The surgical team often consists of people with different body heights. Frequently, the height of the operating table is adjusted according to the height of the surgeon. However, this working height is not always optimal for the remaining members of the team and can lead to ergonomically poor conditions. The working surface height relative to a subject performing manual work determines the upper extremity effort and the potential for musculoskeletal injury. Additionally, because operating tables were originally designed for open surgery, they are not optimal for minimally invasive procedures. The operating tables are adjustable in height to between 725 and 1,215 mm [2].

A previous study showed that the discomfort and difficulty ratings were lowest when instrument handles were positioned at the elbow height of the surgeon [7]. With regard to the guideline of positioning the instruments at elbow height, the ergonomic operating surface height (defined as the navel height of the patient lying on the operating table while the abdomen is filled with carbon dioxide [CO_2]) lies between 0.7 and 0.8 of the operator/assistant's elbow height (650–1000 mm) [17]. It is obvious that current operating tables cannot adjust low enough to satisfy the ergonomic guidelines, thus changing the relation between the height of the surgeon's hands and the desirable height of the operating table [17].

The crowding in the operating theater and the positioning of the surgical team around the operating table also contribute to the aforementioned problems. Alarcon and Berguer [1] concluded that there is a significant trend toward increasing operating theater crowding during laparoscopy. The percentage of operating theater space occupied by furniture, equipment, and persons increased from 36% for open surgery to 41% for laparoscopy. The median number of pieces of equipment present in the operating theater increased from 6 for open procedures to 13 for laparoscopic procedures, reflecting the increased dependence of minimally invasive surgery on technology [1]. Additionally, the freedom of positioning the surgical team and equipment around the operating table is limited because the base of the operating table is fixed to the floor.

This study aimed to develop an ergonomic body support that supports surgeons during both open and minimally invasive procedures, reduces the surgeon's muscle activity in the lower back and extremities, and solves problems related to nonoptimal working height.

Materials and methods

During the design process, the participatory design approach was used. This approach involves the user group throughout the whole design process to help ensure that the product designed meets their needs [14]. The surgeons of the Erasmus Medical Centre were closely associated with this study. After a literature study, observations, interviews, and analysis of the current situation, a couple of design criteria were formulated. On the basis of these design criteria, a prototype was built. The feasibility of this prototype was assessed during surgical procedures in the operating theater, and a questionnaire was used to record the value of the prototype as perceived by the participating surgeons. Furthermore, electromyography (EMG) recording was accomplished with one subject using the prototype.

Design criteria

The most important design criteria were as follows:

- Support for the body of the surgeon in a natural working posture
- A product suitable for use during both open and minimally invasive procedures
- Compact construction of the product because of the limited space available around the operating table
- Comfortable and safe use of the product by both the P_5–woman (5th percentile of short women) and the P_{95}–man (95th percentile of tall men) (percentiles of the Dutch population with regard to body length) [13]
- A height-adjustable platform to solve the problems related to nonoptimal working height
- Sufficient space for positioning of foot pedals for electrosurgery
- A product mobile by means of wheels.

Supporting principles

Taking for granted that surgeons have a head- and back-bent posture during open procedures, support for the surgeon's upper body is obvious. According to biomechanics, a head support is the most effective in reducing the muscle activity in lower back. However, this way of supporting is not desirable because the surgeon's freedom of movement will be reduced dramatically. Additionally, this also will lead to an extra couple (torque) in the neck. Nevertheless, the upper body still must be supported as high as possible. Supporting the upper body at chest height is a viable option because the remaining part of the upper body consists of soft tissue. Pressure due to the supporting force on the soft tissue will not be experienced as comfortable.

Because surgeons have an upright body posture during minimally invasive procedures, it is obvious that they should be supported in the semistanding position. In addition, this way of supporting allows the surgeon to operate in the ergonomic manipulative zone [9]. The choice of the chest and semistanding support is described in more detail elsewhere [3, 4].

Development of the ergonomic surgeon's body support

On the basis of the formulated design criteria, different sketches were considered. The involved surgeons of the Erasmus Medical Centre have chosen the represented idea. Development of this idea has led to different concepts, the most likely of which is illustrated in concept phase 1. Elaborating the principle in more detail has resulted in the concept demonstrated in phase 2. The final design presents the completely worked out product. Figure 1 shows an impression of the design process.

Prototype

Further development of the concept in detail has finally led to the building of a functional prototype (Fig. 2). The body support consists of different parts. The surgeon stands on a platform that can move up and down (as directed by a remote control). There is a chest support, which the surgeon can activate during open procedures by leaning against it. The chest support is adjustable in height and can be removed easily, which allows the surgeon more space during minimally invasive procedures or emergency situations requiring fast removal of the support.

A semistanding support also is integrated into the body support for use during minimally invasive procedures. For positioning and fixation of the foot pedal, metal strips are integrated into the platform. Wheels beneath the base make the prototype fully mobile. When the surgeon stands on the platform, his or her bodyweight causes the wheels to collapse because they are fixed with a spring construction. This solution simultaneously offers stability by standing on the platform and mobility by stepping down.

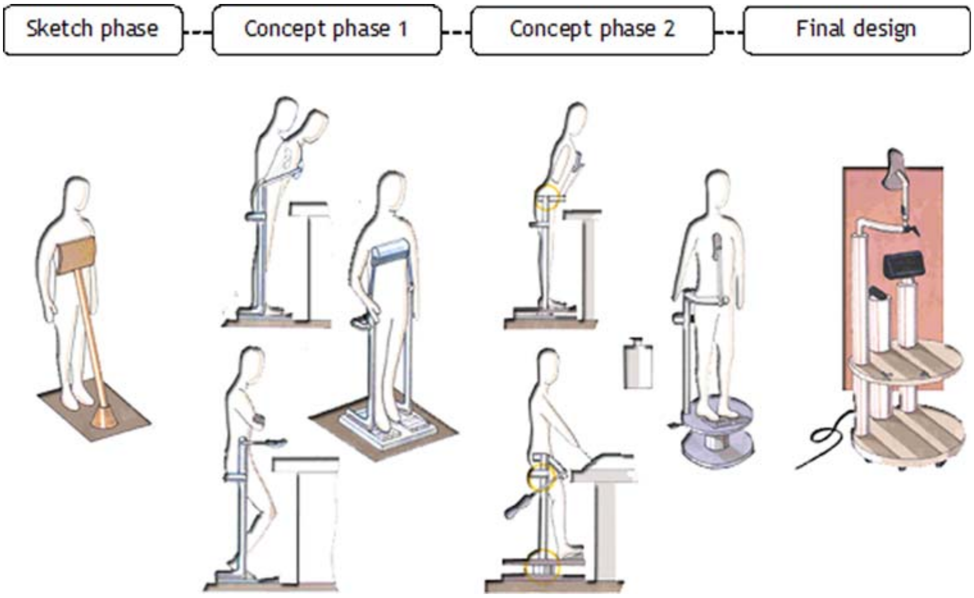


Fig. 1. Design process for the ergonomic surgeon's body support.

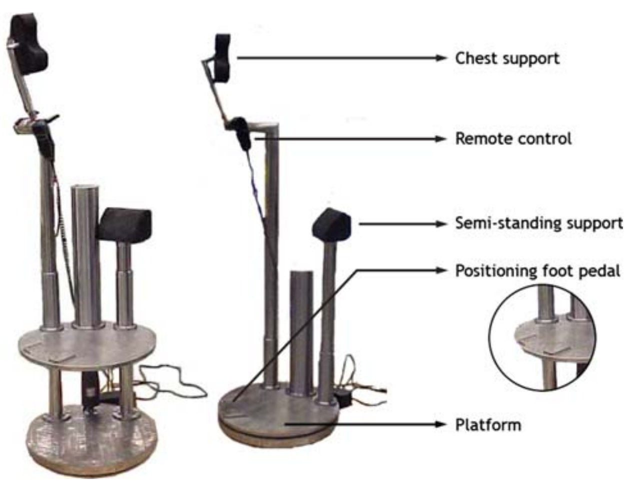


Fig. 2. Prototype of the ergonomic surgeon's body support.

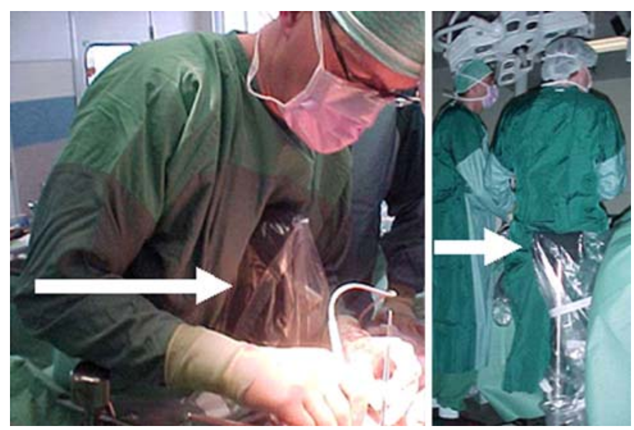


Fig. 3. Feasibility of the prototype during minimally invasive procedures (right side) and open procedures (left side).

The feasibility of the designed ergonomic body support was assessed during several open and minimally invasive procedures in the operating theater of the Erasmus Medical Centre (Fig. 3). For an objective assessment of the prototype, the surgeons involved in developing the body support were excluded from the feasibility study. A questionnaire was used to record the value of the support as perceived by the participating surgeon.

Electromyography

The muscle activity of one subject (P_{50}–man) was measured while he was simulating a surgical task according to a protocol. The measurements for chest support were performed in four conditions:

1. Relaxed standing
2. Bending forward without support (angle 15° and 20°)
3. Bending forward with support on chest height (angle 15°)
4. Bending forward with support on chest height (angle 20°)

The measurements for semistanding support were performed in two conditions: excursion of upper extremities with and without semistanding support. The bending angles and the upper body extremities were measured using a digital protractor type 106 ES (Mahr, Göttingen, Germany).

A selected muscle group was examined in the laboratory by means of EMG recording according to the protocol. To normalize the data for comparison, the maximum voluntary isometric contraction (MVIC) also was measured [11], obtained with manually applied resistance. Before the electrodes were attached, the skin was grated, then cleaned with alcohol. A reference electrode was placed around the left wrist. For the MVIC and EMG recordings, a portable physiologic measurement system, type Porti 5–16/ASD of TMS International B.V. (Enschede, The Netherlands) was used. The Ag/AgCl surface electrodes with recessed pre-gelled (hydrogel) elements (GE Medical Systems Accessories Europe) were used to collect the EMG and MVIC signals. The raw EMG signals (DC frequency, ~2 KHz) were processed electronically with a sample rate of 1,000 Hz, and the cutoff frequency was 10 ± 200 Hz.

The following muscles were examined:

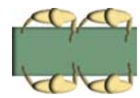
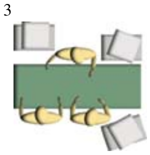
- Eerector spinae muscle (right sides about 2 cm from the midline at the level of L5-S1) [16]
- Semitendinosus muscle
- Gastrocnemius muscle (caput mediale)

Results

Questionnaire

The results of the questionnaire completed by seven independent participating surgeons are presented in

Table 1. Results of the questionnaire

	Subject							Set-up
Personal	1	2	3	4	5	6	7	1
Gender	F	F	M	M	F	M	M	
Height (m)	1.80	1.66	1.88	1.90	1.60	1.82	1.80	
Weight (kg)	77	52	82	85	55	80	80	
Surgeon/Resident	R	S	S	R	S	S	R	
Procedure								
Kind of surgery	O	O	O	O	O	MIS	MIS	
Positioning surgical team	1	1	2	2	2	3	3	2
Time of usage of body support								
Total OR time	270	180	380	380	120	70	80	
% OR time	57%	44%	27%**	63%**	68%	22%	25%	
Judgment								
Comfort overall	Yes	Yes	Yes	Yes	Yes	No	Yes	
Comfort chest support	Yes	Yes	Yes	Yes	Yes			
Comfort semi-standing support	Yes	Yes	Yes	Yes	Yes	No	Yes	
Comfort to use foot pedal						Yes	Yes	3
Restriction of movement***	U	U	U	R	R	R	R	
Future use	Yes	Yes	Yes	Yes	Yes	Yes****	Yes	
Safety	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Simplicity	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

O = Open surgery
MIS = Minimally invasive procedure
** These two surgeons have alternated during the procedure
*** U = unrestricted, R = restricted
**** After processing his suggestions in the product

Table 2. Reduction of muscle activity during bending forward without chest support

Forward bending angle with chest support	m. erector spinae	m. semitendinous	m. gastrocnemius
15°	40%	26%	77%
20°	48%	14%	70%

Table 1. The results are divided into four categories: personal information about the subjects, type of surgery and the positioning of the surgical team during the procedure, total operating time, and time of prototype usage as a percentage of the total operating time, and finally the judgment of the participating surgeons. The "comfort" judgment is based on the extent of overall discomfort reduction using the prototype and the user-friendliness of different parts of the prototype. For this reason, the "comfort" judgment is divided in four subgroups:

1. Overall comfort
2. Comfort during the use of chest support
3. Comfort during the use of semistanding support
4. Comfort during the use of the foot pedal.

Electromyography

The results of the EMG recording for the three measured muscles (erector spinae, semitendinosus, gastrocnemius muscles) with and without use of the chest support are shown in Fig. 4 as percentages of MVIC.

The minimal muscle activity for all three muscles occurs during relaxed standing. When the surgeon bends forward without support, the muscle activity increases proportionally with the bending angle. Use of the chest support reduces the muscle activity systematically (Table 2).

The results of the EMG recording for the three measured muscles (erector spinae, semitendinosus, gastrocnemius muscles) with and without the semistanding support are shown in Fig. 5 as percentages of MVIC. The semistanding support is effective in reducing muscle activity in the leg muscles, especially the calf muscle (Table 3).

Discussion

In general, the risk factors for musculoskeletal injury include nonergonomic body postures, frequent awkward repetitive movements of the upper extremities, and prolonged static head and back postures. In addition, surgeons experience cardiovascular stress during procedures, and the magnitude of this stress can exceed the level of aerobic physical work performed [5]. The fact that surgeons are performing surgery so concentrated that they tend to neglect their posture increases the need for body support.

Our design vision has resulted in the development of an ergonomic body support for surgeons that is suitable for use during both open and minimally invasive procedures. Only a few studies have dealt with support for the surgeon's body. In a previous study, the design of an ergonomic surgeon's chair was discussed, but it did not

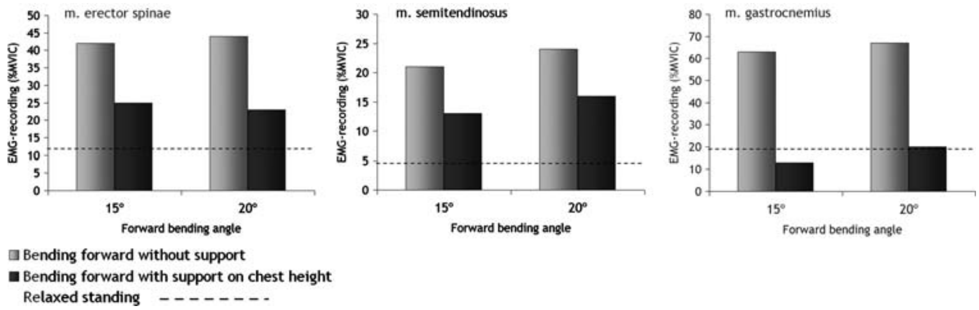


Fig. 4. Results of electromyography (EMG) recording for one subject (P_{50}–man) with and without the chest support.

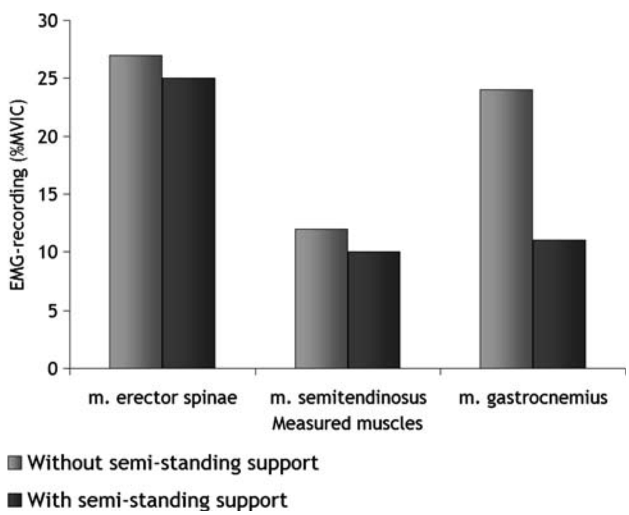


Fig. 5. Results of electromyography (EMG) recording for one subject (P_{50}–man) with and without the semistanding support

Table 3. Reduction of muscle activity using the semistanding support

	Muscle		
	Erector spinae	Semitendinosus	Gastrocnemius
With semistanding support (%)	5	12	50

provide any information about the effect of body support on the reduction of muscle activity [15].

The results of our study imply that supporting the body by means of a chest support is effective in reducing the activity of the lower back and leg muscles during open surgery. The desired effect of the chest support is closely related to the optimal height of the support [3, 4]. According to the variation in body lengths, the chest support must be adjustable in a range of 40 cm (0.8 × P_5–woman shoulder height and 0.9 × P_{95}–man shoulder height) [3, 4]. The semistanding support shows a trend of reduced leg muscle activity similar to that for the chest support. Conversely, the contribution of the semistanding support to the reduction in activity of the erector spinae muscle is very limited.

Minimally invasive surgery has been adopted in operating theaters without any proper adjustments of their design and layout. Because the current operating tables are originally designed for open surgery, they are not optimal for minimally invasive procedures with regard to ergonomic guidelines. The current operating tables are adjustable in height to between 725 and 1,215 mm [2]. A previous study showed that the discomfort and difficulty ratings were lowest when instruments handles were positioned at elbow height of the surgeon [7]. With regard to the guideline of positioning the instruments at elbow height, the ergonomic operating surface height (defined as the navel height of the patient lying on the operating table while the abdomen is filled with carbon dioxide [CO_2]) lies between 0.7 and 0.8 of the operator/assistant's elbow height (650–1000) [17].

It is obvious that the current operating tables cannot be adjusted low enough to satisfy ergonomic guidelines. According to Berguer et al. [7], redesigning of surgical tables or the operating room workspace is required to optimize the postural ergonomics of minimally invasive surgery. However, this is an expensive and time-consuming approach that may interfere with adoption of this solution by the hospitals. A much cheaper and more effective solution for this problem is to position the surgeon on a height-adjustable platform.

The platform of the body support is adjustable in height by means of a motor that can be operated by a remote control. This remote control is packed in a sterile cover, allowing the surgeon to adjust the height of the platform independently of assisting personnel during the procedures. The platform is powered from the main supply, and the height of the platform ranges from 60 mm (minimum) to 460 mm (maximum), meaning that 95% of the user group will have a comfortable posture (in combination with the current operating tables). The semistanding support at the buttocks has a maximum height of 900 mm when the platform is positioned in the lowest position for a tall surgeon. The height of the semistanding support is proportional to the height of the platform. This allows optimal placement of this support for the whole user group.

Due to the positioning of the equipment during both kinds of procedures, surgeons have a limited space around the operating table for movement, which elicits a static body posture. Taking into account the limited space available in the operating theater, the body support must be designed as compactly as possible. The design criteria (body support as compact as possible, comfortable and safe use by 95% of the user group, and sufficient space allowed for positioning of the foot pedal for electrosurgery) are contradictory conditions. The platform must be large enough for comfortable and safe standing by a tall surgeon while allowing sufficient space for positioning of the foot pedal. On the other hand, it must be as compact as possible considering the limited space.

Nevertheless, a compromise was reached by designing the platform with a diameter of 55 cm. The platform is large enough for a P_{95}–man (tall surgeon) to stand comfortably without falling and for positioning of the foot pedal, yet sufficiently compact to be used in the limited space around the operating table.

Despite the compactness of the prototype, all seven participating surgeons indicated that the body support is safe in use. A remarkable outcome of the questionnaire is the dichotomy about the restriction of the movements. However, this cannot be dissociated from the positioning of the surgical team during the procedure. On the basis of this observation, it may be concluded that the surgeons with a negative opinion were standing very crowded.

A point of interest for the designer when users are interacting with products is the experienced level of comfort. Van Veelen et al. [18] report that surgeons frequently complain about pressure areas as well as pain and fatigue in hand and lower limb joints from manipulation of instruments for minimally invasive surgery. It should be mentioned that we were particularly interested in one of the interactions between our product and surgeons: leaning against the chest support. This may have consequences for breathing because of the pressure on the chest. Nevertheless, none of the surgeons has experienced discomfort using the chest support.

Conclusions

The optimum working condition for a surgeon is a compromise between the spine and arm positions and the effort and fatigue of their respective supporting muscular groups. The results of this study imply that supporting the body is an effective way of reducing muscle activity, which over the long term may reduce physical complaints and discomfort. Additionally, the product supports the surgeon in his or her natural posture during both open and minimally invasive procedures while solving working height–related problems of the surgical team. Because of the simplicity in its design and compactness, the ergonomic body support can easily be adopted in the current layout of the operating theater.

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