Low invasive surgical techniques were made possible by technical progress and related miniaturization of surgical equipment. Benefits of low invasive techniques are widely known (1, 2, 3). Laparoscopy is the most common low invasive method of surgery. It became a standard management of many diseases. Other surgical techniques that became common recently include single incision laparoscopic surgery (SILS) and natural orifice transluminal endoscopic surgery (NOTES). For many years surgeons have been assisted by robots who fulfill simple tasks (e.g. keeping a camera) or even replace hands of surgeons (RAS – robotic assisted surgery).

When laparoscopy became popular, reports appeared documenting adverse effects of laparoscopic technique on doctors who used it (2). In this paper we review literature on the current state of knowledge in the area of risks related to the use of laparoscopic technique and measures of their prevention to increase the level of safety of this procedure for the patient and to avoid potentially negative effect on the health of a surgeon who performs a low invasive procedure.

Importance of awareness of risks for the surgeon during a laparoscopic procedure

Development of devices and complex tools between a patient and an operator resulted in appearance of new type of physical and mental stress related to work (4, 5). These stresses are referred to as “workload”. With regard to significant physical and mental stresses, work performed by a surgeon is compared to that of a pilot (6, 7). Due to awareness of effect of these stresses on performed tasks, they need to be minimized to provide correct course of a surgical procedure and related patient safety.

Statistical estimates indicate that 30-50% complications in surgical patients could be avoided and general level of human (patient) safety in the health care environment is several fold lowered that in the work environment with comparable risk (7, 8). Among multiple theories attempting to explain origin and correct of errors, the most commonly reported initial cause of error is a non-apparent risk related to simultaneous occurrence of a potentially dangerous situation (6). When an error do occurs, usually there is a so called “cascade of errors” and final damages depend on ability to break the chain of adverse events (9, 10). Therefore awareness of sources of potential errors reduces the chance of their occurrence and if they do occur – ability to act correctly. In view of this awareness, understanding risks related to use of laparoscopic technique provides higher level of safety of the procedure to the patient himself/herself (9, 10).

Another aspect of understanding risks for the surgeon – laparoscopist is ability to prevent phenomena resulting from excessive mental (fatigue) and physical workload at work. Workload from the first group results in erroneous decisions of the operator while from the second group – physical fatigue – results in e.g. imprecise movements. Long-term workload, persisting for months and years, results in motor system disorders related to prolonged
maintenance of weird body positions during a surgical procedure (11).

As a whole, awareness of additional risks related to laparoscopic procedures should result in reduction of workload so as to minimize well known phenomenon of decreased efficiency (increased number of errors) at increasing physical and/or mental workload.

Ergonomics is a branch of science that deals with theoretical side of these issues. The term “ergonomics” was used for the first time in 1857 by a widely accepted creator of ergonomics, a Pole – Wojciech Bogumil Jastrzębowski who originated this name from Greek (ergon = work, nomoz = rule) and defined it as a “science dealing with work – i.e. about using strength and skills provided to a human by the Creator” (12).

There are many obstacles to using ergonomics in surgery despite vast amount of knowledge available on risk factors of operator related errors. The main cause of this phenomenon is that the science requires adjustment of work to a human, while in medicine it is impossible due to multiple considerations (i.e. specific shape of human body / surgical field as a work place, impossible change of an operator following a “recommended” time of work, etc.) (13).

Physical workload during laparoscopic procedure

Physical workload includes processes related to physical exertion and its effect mainly on the motor system. The most common direct causes of excessive and atypical (physical) workload experienced by an operator during a laparoscopic procedure include (13):

1) restriction of operator’s moves – standard, unbroken surgical tools penetrating through the skin, has 4 degrees of freedom;
2) requirement to use excessive force – up to 6-fold higher versus open surgical procedures due to worse mechanical force transmission of the tool itself and due to characteristics of release of force in a hand. In particular weakening of “closing” force of the hand occurs with flexion and ulnar deflection of the wrist (e.g. with angular shafts);
3) requirement for extensive movements (“rowing”) – related to penetration of laparoscopic tools through body walls;
4) lack of adjustment of surgical tools – one size, non-ergonomic handles (sharp edges, often non-intuitive locking mechanisms);
5) non-adjusted work place – often: one monitor on a mobile column near the operating table – position of the monitor cannot be regulated;
6) monotonous movements – most of the movements with tools involve preparation, most often using a thumb (tools with active tips) or whole upper extremity (hook);
7) forced positions with predominance of static positions – as compared to open surgical procedures, laparoscopic procedures require visual fixation on an immobile monitor and, irrespective of head/neck position – stiffening and abduction of arms with hand and wrist mobility (this position is referred to as a „chicken-wing position”). Often it is difficult to control electrosurgical tools with a pedal – European statistics indicate that more than 90% of physicians would prefer another method of triggering diathermy and 3/4 of physicians erroneously select a pedal to trigger appropriate device setting (14).

Ergonomics helps to determine causal relation between the above mentioned factors and musculoskeletal complaints that exist or will exist unless the nature of work is changed.

From the point of ergonomics, view these risks are classified to one of several groups of ergonomic risk factors, i.e. factors that induce MSDs („musculoskeletal disorders”)¹. Some diseases included in the MSD category are also listed by Polish law regulating work performance (i.e. such that result from a particular method of performance of a given task, e.g. laparoscopic procedure). These include e.g. chronic tendonitis, bursitis, chronic periarthritis or humeral epicondylitis.

Table 1 presents risk to the particular body segments² related to a workplace or used tools. It must be emphasized that a high percentage of these factors could be avoided with a simple measures (e.g. change of monitor, column position, height of the operating table, pedal, etc.). The biggest load on the operator body during

¹ This is a collective term including particular diseases of the motor system. These conditions are universally preceded by symptoms – i.e. complaints reported by the employee himself/herself and are not confirmed by a physical examination (e.g. numbness, tingling, etc.) and confirmed by physical examination (e.g. reduced grip strength, reduced mobility, etc.)
² Ergonomic term.
### Table 1. Workload for body segments during laparoscopic procedures

<table>
<thead>
<tr>
<th>Body segment</th>
<th>Cause – work place / tool</th>
<th>Result – position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head / neck</td>
<td>– fixation of vision on the monitor</td>
<td>– hyperextension of the neck/head</td>
</tr>
<tr>
<td></td>
<td>– hyperextension of the neck/head</td>
<td>– lateral neck/head flexion</td>
</tr>
<tr>
<td></td>
<td>– neck rotation / head rotation</td>
<td>– neck rotation / head rotation</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>– requirement for keeping the upper part of the body relatively immobile</td>
<td>– spine rotation</td>
</tr>
<tr>
<td></td>
<td>– uneven placement of body weight (operation / searching for pedals)</td>
<td>– lateral flexion of the spine</td>
</tr>
<tr>
<td>Shoulders and</td>
<td>– work with laparoscopic tools – length of tools, port location</td>
<td>– arm abduction</td>
</tr>
<tr>
<td>arms</td>
<td></td>
<td>– shoulder elevation</td>
</tr>
<tr>
<td>Wrists</td>
<td>– tool handle</td>
<td>– wrist flexion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– ulnar flexion of the wrist</td>
</tr>
<tr>
<td>Hands</td>
<td>– tool handle</td>
<td>– keeping a clenched hand – load for finger flexors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>and/or thenar muscles</td>
</tr>
</tbody>
</table>

Laparoscopic procedures is placed on the vertebral column (cervical and lumbar segment) and upper extremity, in particular shoulder girdle, wrist and hand. Load includes not only awkward postures but also static positions that are somewhat natural manner of keeping balance by a human (unsteady balance).

These data were obtained using results of measurements of load placed on muscle groups (most often using EMG) and subjective surveys (16, 17).

Specifics of surgical training and practice requires acceptance of experienced complaints. This problem is known worldwide. Studies of complaints experienced during surgical procedures, basing on individual questionnaires, conducted among physicians performing laparoscopic procedures (not only surgeons) showed that such complaints were present in nearly of 80% study subjects (18).

Mental stress during laparoscopic procedures

There are the following sources of mental stress during laparoscopic procedures (13):

1) Inversion of movements on a monitor relative to body movements, in a vertical and horizontal plane, so called “lever effect” – as a detrimental effect on eye-hand correlation decreases with increased experience of an operator.

2) Discrepancy between an axis of vision and a working axis of upper extremities – it has been shown when best work parameters are achieved when an axis of vision is compatible with a working axis⁴, and additional factors that need to be considered here include:
   - observed working angle of the tools (tasks are performed within the shortest time when these angles are identical)
   - an angle between a camera (visual axis) and working plane of the tools – optimal 0-15 degrees

3) indirect vision – an image from laparoscopic camera is:
   - two-dimensional – the most evident aspect of two dimensional vision is loss of depth; adequate level of training allows the brain to estimate indirectly the depth, e.g. due to mechanical contact with a tissue, estimation of size and perspective of adjacent structures as well as basing on light reflection and shadows
   - magnification (2-4x) and limitation (60-90 degrees) of the operative field
   - rotation versus the operative fields – along with its increase, irrespective of the degree of experience of the operator, number of errors or decrease of precision occurs and time required to perform them increases.
   - duration of laparoscopic procedures – development of laparoscopic procedures makes the procedures more and more complex.

Increased cumulative physical and mental workload during a laparoscopic procedure leads to so called “surgical fatigue syndrome” that manifested as “mental exhaustion, exces-

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³ or similar

⁴ Due to the nature of laparoscopic technique, this is essentially impossible to achieve
sive irritation, reduced ability for intraopera-
tive assessment and reduced manual skills” (1).

Simple solutions reducing workload during laparoscopic procedures

Current study results indicate that sur-
geons’ awareness of ergonomics is limited al-
though surveys among done surgeons indicate
that they highly rate their own knowledge of
ergonomics. Good example of this discrepancy
was illustrated by a study of ergonomics of
laparoscopic tools: handle A was rated very
high before a subject became acquainted with
a handle B; this situation was reversed when
a prototype handle B was presented – then
handle A was rated markedly lower (17). Qual-
ity of commonly used surgical tools made
surgeons get used to it which makes new solu-
tion difficult to gain recognition. New construc-
tive solutions may be also difficult to accept in
particular by operators who have gained expe-
rience in using existing equipment, adapted
for the purpose of laparoscopic techniques from
classic surgery that became almost unchanged
until nowadays.

It must be emphasized that the isolated fact
of better ergonomics of a tool or its easier use
under experimental conditions (e.g. simulator)
cannot be a sole indicator determining selec-
tion of equipment to the procedure since men-
tal stress related to its use could adversely
affect general level of safety of the surgical
procedure.

There are many results of studies concern-
ing any aspect of surgeon’s work during a
laparoscopic procedure (20, 21). These re-
resulted in preparation of recommendations
concerning mainly item placement at the work
place. These recommendations are aimed at
minimizing workload:
1. Recommendations for the image:
   1) optimal height of monitor placement is
      approximately 10 cm below Frankfurt
      horizontal plane (FHP) of an operator;
      this position is a compromise between an
      optimal plane for correct precision work
      and plane neutral for the motor system
      (in the neck);
   2) distance between an operator and the
      image should not be lower than 0.9 m
      and for 14” monitors should not exceed
      3.0 m; such distances enable correct de-
termination of anatomical details;
   3) the monitor should be placed before the
      operator – therefore the monitor should
      be equipped with an arm, even if it is
      placed on a laparoscopic column;
   4) if possible, assistant should have his/her
      own monitor.
2. Panels of control devices (diathermy, insuf-
   flations) should be in the visual field of an
   operator.
3. Table should be adjusted to the elbow
   height of an operator – this parameter it
   set intuitively in most cases.
4. Method of use and localization of pedal
   should be considered (loss of contact with
   pedal keys results in concern in more than
   half of the operators) – permanent location,
inactivation of one key when we use only
one of modes of diathermia.
5. Surgical tools – if possible, tools used to hold
   the tissues should have locks and adequate
   jaw parameters to prevent tissue slipping
   from the tools and use of excessive force.
6. If possible, operating rooms specially de-
   signed for laparoscopic procedures should
   be used.

Ergonomic solutions are eagerly introduced
in many work places because their benefits are
obvious. Their use on the ground of surgical
technique is still not very popular. This is
mainly due to low ergonomic awareness of the
surgeons, variable settings and level of educa-
tion of laparoscopic surgeons. As far as any
chance to reduce the risk of error by the op-
erator during the laparoscopic procedure is
worth exploration, the most clear benefits (i.e.
surgical method that is not detrimental for the
surgeon’s own health) from these recommenda-
tions will mainly be found by laparoscopic
surgeons.

In the era when quality of life is much ap-
preciated, laparoscopic surgeons should be
interested in ergonomic solutions to protect
their own health and patient safety during
laparoscopic procedures.

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5 This is the plane established when right and left poria
   and left orbitale are in the same horizontal plane
   (Latin planum horizonale frankfurtesens)

6 This is the height between the floor and olecranon with
   the upper extremity flexed at the right angle.
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