MINIMALLY INVASIVE SURGICAL END-EFFECTOR COMBINING SCISSORS, HOOK AND GRASPER

1.0 Abstract

The use of single-functional instruments during Minimally Invasive Surgical (MIS) procedures, where each instrument is capable of performing only one particular function, requires the surgeon to make a lot of instrument swaps during one operation to carry out all the required functions. This results in increased operation times and increased danger of hitting the human organs unnecessarily. To overcome this problem, efforts have been made towards combining a number of end-effectors in one instrument to produce a multi-functional instrument. This invention, nicknamed **UMMISEF (for University of Malta Minimally Invasive Surgical End-Effector)** aims to contribute in this direction through the design of a novel laparoscopic instrument which combines the underlying working principle of three commonly used MIS end-effectors, namely the scissors, hook and grasper in one multi-functional instrument. The novelty of this invention lies mainly in the particular combination that is used, which will help the surgeon to perform less instrument swaps and therefore will reduce operation times considerably. The combination of functions which can be performed by the **UMMISEF** instrument also makes it possible for it to be used in other applications, apart from surgical, that require the use of cutting, lifting and grasping functions in a constrained environment e.g. wiring, maintenance and repair.

1.1 Abbreviations

ABBREVIATION	DEFINITION
CA	Clip Applier
CO_2	Carbon Dioxide
G	Traditional end-effector Grasper
G_U	UMMISEF grasper concept
H	Traditional end-effector Hook
H_U	UMMISEF hook concept
L	Laparoscope
LC	Laparoscopic Cholecystectomy
MIS	Minimally Invasive Surgery/Surgical
S	Traditional end-effector Scissors
S_U	UMMISEF scissors concept
UMMISEF	University of Malta Minimally Invasive Surgical End-Effector

1.2 Glossary

TERM	EXPLANATION
Electro cauterization	The process of destroying tissue using heat conduction from a metal probe heated by electric current. The procedure is used to stop bleeding from small vessels or for cutting through soft tissue.
End-effector	The part of the laparoscopic instrument (generally found at the tip of the

	instrument, inside the patient) which performs the actual manipulation e.g. cutting, lifting, holding.
Laparoscope	Camera that is inserted inside the patient to view the organs and tissues via a monitor.
Laparoscopic Cholecystectomy	Surgical intervention that involves the removal of the gall bladder.
Minimally Invasive surgery	Surgery that is performed under indirect vision (via a camera and monitor) and indirect manipulation (using very tiny end-effectors) to perform tiny incisions in the patient for smaller scars and other benefits.
Trocar	A hollow tube with a seal (to keep CO_2 from leaking) through which instruments are inserted into the patient's abdomen during laparoscopic procedures.
Verres needle	A needle used to pierce the patient's abdominal wall during laparoscopic procedures.

2.0 Field of invention

MIS offers a number of benefits to the patient over open surgery due to smaller incisions that are performed that result in less bleeding and smaller scars and less chances of infections and post-operative complications. Shorter recovery times also imply shorter hospital stays and reduced hospital costs. However, besides these advantages, there are a number of drawbacks for the surgeon who uses the MIS instruments, which arise due to the fact that indirect vision and indirect manipulation are used during MIS. From surgical observations that were carried out, it was observed that during MIS, surgeons make use of a range of single-functional instruments, each instrument capable of performing one particular function. These instruments need to be inserted and retracted out of the body via the trocars many times. There are many drawbacks to this, such as the fact that the surgeon loses train of thought of the surgical site and that there is an increased risk of hitting organs unnecessarily. However one of the greatest drawbacks of using single-functional instruments is that the operation time is lengthened. A study carried out by Melzer (cited in Frecker et al 2005[1]) showed that swapping takes about 10 to 30% of the total time of an MIS operation because of a high degree of instrument swapping that needs to be carried out. To be able to reduce the number of swaps required, a feasible solution is to make use of a multifunctional instrument that performs more than one function. Slater (1993)[2] has come up with a multifunctional instrument that combines a scissors and hook whereas Yoon (1999)[3] has combined a grasper and scissors. On the other hand Frecker et al

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[1] Frecker, M., Schadler, J., Haluck, R.S., Culkar, K. and Dziedzic, R. Laparoscopic Multifunctional Instruments: Design and Testing of Initial Prototypes, *Journal of the Society of Laparoendoscopic Surgeons,* no.9, 2005, pp. 105-112.

[2] Slater, C., 1993. Laparoscopic Hook Scissors. United States Patent, Patent No. 5,203,785.

[3] Yoon, I., 1999. Multifunctional Grasping Instrument with Cutting Member and Operating Channel for use in Endoscopic and Non-Endoscopic Procedures. United States Patent, Patent No. 5,984,939.

(2007)[4] have developed an instrument that combines a grasper, dissector and scissors. From surgical observations carried out and interviews with practicing surgeons, **the combination of scissors, hook and grasper** results in a drastic reduction in the number of swaps. From the literature search carried out, this combination is novel.

3.0 Background of invention

Laparoscopic procedures are operations in the abdomen that are carried out minimally invasively. From a summary of the operations that took place at the Maltese general hospital compiled by Janulova (2005, 2006, 2007)[5], it was found out that the amount of laparoscopic cholecystectomy (LC) procedures (for removal of the gall bladder) is on the increase. This, together with the fact that **a lot of instrument swapping takes place** during these procedures (see Table 1) due to many functions that need to be performed in order to manipulate the gall bladder, encouraged the researchers to look further into these operations. To be able to understand the swapping problem, a 'clinically driven approach' was used whereby researchers entered the operating theatre to be able to observe surgeons, while the latter carried out a number of LCs, and took note of the number of swaps that were done and which instruments were being inserted and retracted out of each trocar.

The traditional LC procedure involves the following steps:

a) Initially four incisions (marked as A, B, C and D in Figure 1) are performed via the verres needle of the trocars;

b) Through one of the incisions, insufflation is carried out – that is carbon dioxide (CO_2) is injected to blow up the abdomen and increase the space for the surgeon to operate and allow better viewing of the organs. CO_2 is used because it is absorbed readily by the body and excreted easily by the lungs, it is transparent in colour and thus does not interfere with the surgeon's view, and it is non-flammable;

c) Graspers are passed through incisions A and B to grasp and elevate the gallbladder;

d) A laparoscope (camera) is passed through incision D;

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[4] Frecker, M., Haluck, R., Dziedzic, R. and Schadler, J., 2007. *Multifunctional Tool and Method for Minimally Invasive Surgery.* United States Patent, Patent No. 2007179525.

[5] Janulova, 2005. *Surgical Operations Annual Report 2004,* Malta: Data Management Unit, St Luke's Hospital.

Janulova, 2006. *Registered Surgical Operations Annual Report 2005,* Malta: Data Management Unit, St Luke's Hospital.

Janulova, 2007. *Registered Surgical Operations Annual Report 2006,* Malta: Data Management Unit, St Luke's Hospital.

e) Instrument swapping occurs through incision C due to the number of actions that need to be performed such as separating the excess tissue around the gall bladder, cutting the cystic artery and cystic duct, freeing the gall bladder and removing it once it has been freed.

Typical LC procedures make use of instruments that consist of an end-effector, a working shaft and a handle, as illustrated in Figure 2. The end effector typically consists of one or more jaws, which are actuated by means of the handle via the working shaft. The jaws are typically connected to a pin, that moves along an angled slot, and which is connected to an inner rod in such a way that when the handle of the instrument is actuated the jaws are opened and closed.

4.0 Summary of the invention

The invention being claimed concerns the end-effector of such an instrument. As stated in Section 2.0, the solution that has been developed includes **the combination of a hook, scissors and grasper**, different embodiments of which are shown in Figure 3.

The following notation shall be used for this section and throughout the remainder of this document:

S = traditional end-effector scissors
S_U = UMMISEF scissors concept
H = traditional end-effector hook
H_U = UMMISEF hook concept
G = traditional end-effector grasper
G_U = UMMISEF grasper concept
CA = clip applier
L = laparoscope
U = UMMISEF combination

The following functions are carried out by each instrument (as shown in Table 2):
S – is used to cut through the tissue, ducts and arteries;
H – is used to lift the tissue and separate the excess tissue that blocks other organs;
G – is used to hold the tissue in place.
Table 3 compares the number of swaps that need to be done using single-functional instruments to the number of swaps that need to be done using the claimed UMMISEF multifunctional instrument, showing that the number of swaps is reduced from 10 to 6, thus a typical reduction of 40% ((10 swaps – 6 swaps)/10 swaps x 100%) can be achieved.

To better explain the invention being claimed, the following sections will elaborate details on the different parts forming part of the UMMISEF instrument.

Detailed drawings of UMMISEF including the dimensions are attached in Appendix A.

4.1 Description of the UMMISEF scissors (S_U)

The scissors, which is one of the three main components of the novel laparoscopic end-effector, is an instrument that is very frequently used both in MIS and open surgical procedures. In this invention, S_U is made up of two blades – one protruding from the upper jaw and the other embedded in the side face of the lower jaw (as shown in Figure 4).

As well stated by Mishra (2008)[6], the use of S in MIS is quite restrictive. First of all, the surgeon has to be more skilled as lack of experience may cause unnecessary bleeding and damage to important structures given the small space available. Secondly, and more importantly, the design of S should be such that cutting is only performed when required and not, for example, during insertion and retraction of the instrument from the abdomen. To ensure this, in the invention being claimed, the protruding edge of S_U is retracted from the edge of the jaw (distance (1) in Figure 5) so that no cutting is performed during insertion and retraction of the instrument.

As shown in Figure 5, S_U is of the "straight" type which is quite commonly used for cutting and dissection in MIS. Furthermore, since to perform the cutting action a contact point is required between the two blades of S_U, the surface of the lower jaw is inclined at a 5° angle towards the upper jaw (angle (2) in Figure 6). Another feature of the protruding blade of S_U is the tapered part at the edge (feature (3) in Figure 6), which mainly serves to increase the strength and avoid chipping of the blade (since a pointed edge would have been very fragile). Other features are included in S_U to make the parts more easily manufactured by conventional equipment such as milling machines. These include the rounded feature at the start of the blade (feature (4) in Figure 6) and the straight face at the bottom of the blade (face (5) in Figure 6). Moreover, the upper jaw has been designed to contain a through slot (as shown by feature (6) in Figure 7) so that the surgeon is able to see the tissue being cut during the cutting action via the camera and monitor.

4.2 Description of the UMMISEF grasper (G_U)

The grasper, which is used by the surgeon to keep the tissue and other organs in place, is the second main component of the novel end-effector. As can be seen in Figure 3b (i), this component which, in the preferred embodiment, is made up of an array of ribbed teeth on each jaw, is placed further away from the pivot compared to S_U. The reason for this arrangement of G_U and S_U is because while in the case of S, more force is necessary to cut through tissue, ducts and arteries, in the case of G, this force should be limited so that no damage is done to the grasped object. This reasoning behind the concept is illustrated in Figure 8, which shows the difference in pressure applied on the grasped object between concept (a), in which G is placed close to the pivot and concept (b), in which G is placed further away from

[6] Mishra, R. K., 2008. *How do scissors work?,* World Laparoscopy Hospital http://www.laparoscopyhospital.com/PR03.HTM [Online].

the pivot. De Visser (2003)[7] states that the jaws should be designed in such a way that tissue is allowed to protrude at their backside. Therefore an extra section (feature (7) in Figure 9) was added behind the ribbed teeth of G_U to allow for this.

Consideration is also given to the shape and height of the teeth of G_U used. The profile height of the ribbed teeth is 0.3mm following De Visser's design guidance for grasper jaws. As well stated by Pierce (1999), traumatic G which are described as "G having at least one tissue penetrating element on one jaw", are effective for tissue manipulations but are capable of producing unwanted effects e.g. puncturing or tearing of delicate tissue. Therefore, ideally the tissue should be manipulated without having its structural integrity affected. This can be performed by an atraumatic G, which is capable of creating friction but which is not sharp enough to make incisions in the tissue. However, according to Pierce (1999)[8], atraumatic G are also capable of undesirable effects. These generally result from the grasping force being too large, thus creating a point load on the tissue which may damage it.

To avoid the effects of traumatic G, an atraumatic G_U is used in the invention being claimed. The atraumatic design was achieved by adding fillets of 0.1mm radius to the crests of the ribbed teeth. The troughs of the ribbed teeth also have a fillet radius of 0.1mm to make it easier for cleaning and removing any debris when the end-effector is used in reusable instruments. Furthermore, to limit the negative effects which may be induced by the atraumatic G_U, a step (feature (8) in Figure 9) is designed behind G_U to allow some clearance between the teeth when pressure is applied.

Another embodiment of G_U is such that instead of having a ribbed surface texture, other surface textures such as diamond surface texture (as illustrated in Figure 3b (ii)) is used.

4.3 Description of the UMMISEF hook (H_U)

The last main component of the end-effector is the hook, which, as shown in Figure 10, is placed in front of G_U. An issue to consider when incorporating H, is that the latter is generally made up of only one jaw, and therefore, as opposed to the previous two components, only requires one jaw. In fact, in an evaluation carried out at the Maltese general hospital, where the idea of having two H_U (one on each jaw) was presented, one of the surgeons commented that having one H_U is enough and that two H_Us would create problems when the instrument is heated up for electro cauterization.

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[7] De Visser, H., 2003. *Grasping Safely: Instrument for Bowel Manipulation Investigated*, Ph.D., Delft University of Technology.

[8] Pierce, J., 1999. *Micro Traumatic Tissue Manipulator Apparatus*. United States Patent, Patent No. 5893878.

To overcome these problems, the preferred embodiment includes H_U that is placed on the lower jaw while the upper jaw is truncated just in front of G_U (as shown in Figure 10). Furthermore, as illustrated in the cross-section of H_U in Figure 11, all convex corners of H_U (for example, corner (9) and corner (10) in the figure) are rounded so that damaging of the tissue by sharp corners while it being grasped is avoided. Concave corners (for example corner (11) in Figure 11) are also rounded to prevent debris from being trapped inside them.

Another feature of H_U is the retraction at the back (illustrated by distance (12) in Figure 11), which aims to serve several purposes. First of all, with this design, H_U is kept close to the centre of the jaw, thus providing the instrument with better stability. Secondly, this allows the back of H_U to have sufficient thickness (illustrated by distance (13) in Figure 11) to possess the necessary tensile strength.

Another embodiment of H_U is such that apart from the lower jaw, the upper jaw also consists of a hook (as illustrated in Figure 3a (i)). Such an embodiment can be used in applications that require the use of two hooks, such as gynoscopy.

5.0 Application of invention

Although the invention was carried out following observations that were made for LC operations, yet its application need not be restricted to this type of operation only. The claimed end-effector can also be used by surgeons to perform other MIS endoscopic operations that use the combination of S, H and G such as in gynoscopy which is carried out in the female reproductive system to operate the cervix, uterus and fallopian tubes.

H_U can also be used as a dissector to separate the tissue (downwards motion) rather than elevate the tissue (upwards motion). So in this case, the claimed end-effector can also be used in operations that make use of a dissector rather than a hook.

Moreover, U could be used for other applications – not only surgical – that involve functions of cutting, lifting and grasping (e.g. for wiring applications, maintenance and repair in constrained environments).