Abstract
Introduction
Our purpose was to study the surgical anatomy of the deep brain stimulation technique, focusing on the extracerebral part of this minimally invasive procedure.

Materials and methods
Our study was based on four formalin-embalmed adult human cadavers from cadaver donors. We created a set of deep brain stimulation-like materials for the extracerebral technique and formed a step by step diagram of the extracerebral surgical procedure. We also studied the course of the supraorbital nerve.

Results
A small intermediate incision at the midpoint of each tunnel significantly helps in decreasing the procedure’s duration and risks. The lateral limit of the subclavicular pocket’s incision must be vertical to the cervical tunnel axis in order to avoid accidental traumatism during tunneling. Information regarding the supraorbital nerve and skin landmarks of the head, for safer pins or fiducials’ placement, is also provided.

Conclusion
The extracerebral surgical technique hides uncommon anatomical details and difficult technical points. Their knowledge can help neurosurgeons in decreasing the observed complication rates.

Introduction
Deep brain stimulation
The deep brain stimulation (DBS) technique is an established procedure in the treatment of a wide variety of movement disorders and pain. It has been shown to have many advantages over lesioning, mainly its non-ablative nature and reversibility. More specifically, it has become a routine therapy for Parkinson’s disease and, during the first decade of the 21st century, has been further extended to other applications (psychosurgery targets), owing not only to its reversibility but also its easy-to-dose effect. Nowadays DBS, whose therapeutic outcome is directly related to electrode implantation accuracy, attracts great attention and can perhaps be considered as one of the most promising neurosurgical procedures of the 21st century.

Combinations
The overall surgical complication rate of the DBS technique has been reported to be 17.8%, containing minor and major wound problems, hardware-related problems, minor and large bleeds, neurological deficits, failure to benefit from the procedure and complications unrelated to the procedure. However, the surgeon’s experience and hardware improvements have significantly reduced complications over time. The surgeon’s experience is, in fact, considered as the most important factor.

Widely reported long-term complications following implantation of DBS hardware include breakage of electrode leads, implantable pulse-generator (IPG) failure, skin erosions and infection. Wire tethering, or ‘bowstringing’, is an under-recognised complication of DBS-hardware implantation, often necessitating surgical revision. Other problems arising from the extracerebral DBS implanted materials are: impairment of certain movements, cosmetic deformities, discomfort caused by the safety belt, discomfort when directly lying on the IPG and lead-extension related pain. Intracerebrally, it should be noted that in bilateral DBS implantation, brain shift effects can cause misallocation of the second electrode with the risk of adverse or no stimulation effects as well as unnecessary cortical damage.

Surgical anatomy
In order to maximise the acceptability of DBS surgery, improve the risk-benefit ratio and minimise the cost of this procedure, efforts must be made to identify and address all factors leading to complications. In this direction, we believe that a good working knowledge of the surgical anatomy of the DBS technique could be really helpful. Although the anatomy of the extracerebral part of the procedure seems simple, a more careful view can reveal interesting anatomical details and technical issues, which could assist the neurosurgeon in improving the surgical technique and avoiding some of the complications. Our purpose was to study the surgical anatomy of the DBS, focusing on the extracerebral part of this minimally invasive procedure. We tried to explore technical difficulties from an anatomical point of view and reveal anatomical secrets practically useful to neurosurgeons.

Materials and methods
This work conforms to the values laid down in the Declaration of Helsinki (1964). The protocol of this study has been approved by the relevant ethical committee related to our institution where the study was performed.

Our study was based on four formalin-embalmed adult human cadavers, 67–91 years old, two males and two females, which we had (2009–2010) in the dissection room of our department. They come from cadaver donors for students’ education.

In order to study the surgical technique, we carefully reviewed a set of DBS-like materials (not functional) for the extracerebral part of the technique (of a hypothetical DBS application targeting the nucleus accumbens bilaterally). Utmost care was taken to match our materials with the sizes, shapes and materials described in the Medtronic (Medtronic Inc., Minneapolis, Minnesota, USA) manuals.9-12 This DBS-simulation set consisted of models representing the following equipment: IPG (Kinetcra), two lead (3387), two extension wires (7482A), extension passer (cervical), obturator (cervical), obturator tip (cervical), carrier (cervical), lead passer (head), obturator (head), obturator tip (head), carrier (head), two cylindrical boots, two closed boots and two mini plates with four screws.

We also used standard surgical equipment such as scalpels (No 4), scalpel blades (No 24), scissors, forceps, needle holders, absorbable sutures (polyglycolic acid [PGA] 2/0), non-absorbable sutures (Nylon 3/0, 4/0) and other materials comprising of a measure, a syringe (5 ml), blue ink, an electric drill and shaving materials.

Moreover, we carefully reviewed the literature about the DBS surgical technique. Consequently, the outline of the described procedures represents a summary of common practices from the literature. We also studied the related instructions of the Medtronic manuals and finally formed a step by step diagram of the extracerebral surgical procedure (for bilateral DBS using a single IPG), including technique variations or differentiation described in the literature. The step by step procedure is described below:

**Lead implantation**
1. Position of the patient (supine, knees flexed, head elevation)
2. Shaving at the area where the incisions will be placed
3. Drawing of the midline, burr holes (diameter 10 mm, located 25 mm laterally to the midline) and incisions (length 3 cm, hole’s centre = incision’s midpoint)
4. Ink injection in the centre of each burr hole
5. Incision of the skin and deeper layers up to the skull
6. Preparation of a subgaleal pocket at the parietal region (with a diameter of about 5 cm)
7. Drawing of each burr hole just anterior to the coronal suture
8. Burr holes drilling
9. Incision of the meninges
10. Marking and observation of the revealed brain area and vessels
11. Placement of electrodes’ analogues (their extracerebral parts)
12. Lead secure with mini plate analogues and screws
13. Creation of a parieto-occipital tunnel where the wires are inserted and secured with non-absorbable sutures (Nylon 3/0)
14. Coiling of the excess wire within the subgaleal pocket
15. Closure of the meninges
16. Suturing of the periosteum and the above layers with absorbable sutures (PGA 2/0)
17. Skin suturing (Nylon 4/0)

In one case, we applied a single semi-linear skin incision (see ‘Discussion’ for details) instead of two discrete incisions for placement of the Burr holes, in order to examine the results of a technique variation. Entry points were marked on the brain surface after incision of the dura matter.

**Pulse generator implantation**
18. Drawing of the IPG pocket incision with the body in sitting position, 2 cm subclavicularly and 4 cm laterally to the midline (incision length: 8 cm)
19. Body position: supine, the head turned to the opposite side
20. Subclavicular skin incision
21. Preparation of the subcutaneous pocket and insertion testing of the IPG
22. Small retroauricular incision, creation of a secondary pocket and a tunnel up to the main (initial) pocket
23. Connection of the wires superiorly behind the ear and placement of the connectors into the secondary pocket, where they are secured to the periosteum with two non-absorbable sutures (Nylon 3/0) for each one
24. Connection to the IPG and coiling of the excess wire around it (total wire length 51 cm)
25. Placement of the IPG into the subclavicular pocket and securing with two non-absorbable sutures (Nylon 3/0) to the pectoral aponeurosis
26. Suturing of skin incisions (Nylon 4/0 for the head, Nylon 3/0 for the chest)

In one cadaver (female), the subclavicular pocket was prepared on the left side (and consequently, both tunnels as well as the subgaleal and secondary pockets were prepared on this side).

**Landmarks and the supraorbital nerve**
1. Identification of specific anatomical landmarks of the head (lateral canthus-tragus line, line two-finger breadths [3 cm] above the superior orbital rim, skin landmarks of the superior sagittal sinus, transverse sinuses and confluence of sinuses)
2. Identification of important nerves of the head vulnerable to pins or fiducial’s placement
3. Anatomical location and course of the supraorbital nerve at the forehead.
We followed our step by step diagram in carefully practicing the surgical procedure on the cadavers in our department, focusing on the anatomical aspects of each step and examining technical issues from an anatomical point of view.

Results

Lead implantation

Scalp and skull

The use of a syringe with blue ink was very useful for incision marking on the skin (Figure 1) compared to other techniques. During the dissection, we noticed that the subcutaneous fat tissue of the specific head area is rich in small veins (attention should be taken to avoid bleeding during the incision) and that the loose areolar tissue (‘l’ of the ‘scalp’) as well as the subperiosteal adhesions looks like a spider web.

Our anatomical study revealed that the coronal level approximately 10 cm posterior to the nasion, measured with a measure adjacent to the scalp, can approximately provide the desired area for burr holes’ location. The coronal and sagittal cranial sutures were difficult to identify, probably due to the advanced age of the cadavers.

Meninges and brain

The brain area located underneath the burr holes of our study was found to be approximately between the superior and middle frontal gyri, an expected finding. A trajectory through the superior frontal gyrus would more likely lead to a transventricular trajectory. No remarkable arterial branches were observed at the dura matter underneath the burr holes.

Parieto-occipital tunnel

We carefully considered the literature-based notifications (described in our ‘Discussion’) in choosing the materials of our study. We suggest that the parieto-occipital tunnel axon should not be parallel to the burr hole incision and should not begin from the incision’s lateral edge because of the risk of an unwanted lengthening of the incision. Care should be taken not to confuse the subgaleal parietal pocket with the subcutaneous parieto-occipital tunnel. We found that a small intermediate incision (applied in one cadaver), made at the midpoint of this tunnel, remarkably helps in decreasing the procedure’s duration and risks of the subcutaneous tunneling, at a difficult visible area (Figure 2).

Pulse generator implantation

Cervical tunnel

The retroauricular incision (superior entrance of the cervical tunnel) is better to be horizontally located (considering vertical placement of the connectors). Attention should be paid to avoid injuring the occipital vessels during this incision, which were found to pass 6 cm behind the centre of the external auditory meatus. Consequently, it is better for this incision to begin 7 cm behind the ear and expand posteriorly, reaching a total length of 25 mm. We also noted that the placement of the inferior suture at each connector presented difficulties, considering the relatively short length of the retroauricular incision. For such a length, the two sutures of each connector should be placed such that one is placed at the grooved end and the other at the middle (instead of the other end) of the boot. Otherwise, either a single suture can be used (allowing even shorter incision) or a longer incision is needed (e.g. 4 cm).

The most challenging part of the procedure was the cervical tunneling because of its length and the incapability of direct vision. In all cases, tunnels were created at the subcutaneous fat tissue, without traumatizing the superficial cervical fascia. No differences were found in duration or difficulty either starting from the IPG pocket or from the secondary parieto-occipital pocket. However, we noticed that tunneling from its superior entrance increases the probability of leading the driver under the fascia of the sternomastoid muscle.
This muscle in the elderly is usually atrophic and not helpful during the creation of the cervical tunnel.

Cervical tunneling in cadavers necessitated remarkable force. The most difficult area was the midpoint of the tunnel, approximately three fingers above the clavicle. In short necks, a surgeon’s finger from the inferior entrance of the cervical tunnel can reach the above mentioned difficult area. A helpful maneuver was to hold up the above skin with two sutures (preferably absorbable because they are stronger) while pushing the obturator (Figure 3). Moreover, in one of our cases, we made an intermediate incision (according to the relaxed skin tension lines) midway along the tunnel to accommodate the passing of the obturator at a hard point. Because of the short length of the incision (1 cm) and the important easement it provided us, we think it should be taken into serious consideration for future studies (Figure 4).

Subclavicular implantation

The first thing to be done is the design of the subcutaneous pocket for the IPG at the subclavicular region. The IPG should be positioned between the subcutaneous tissue and the pectoral aponeurosis. The pocket must be prepared as close as possible to this aponeurosis so as to not remove the subcutaneous fat from the upper layer, enhancing the protection of the IPG. Careful movements are necessary so as to not accidentally damage the fat, the pectoral aponeurosis or less likely the skin. However, it is preferable to destroy the inferior layer of the subcutaneous fat to avoid injury to the pectoral aponeurosis.

The length of the incision should be about 8 cm. Its lateral limit must be as vertical as possible to the cervical tunnel axis in order to avoid accidental traumatism of the skin during tunneling. We experienced such an episode with one of the cadavers. The supraclavicular skin is relatively vulnerable and should be handled gently. The two dimensions of the pocket have to be at least 1 cm greater than the respective dimensions of the IPG (Figure 5).

The placement of the lateral suture to tie the IPG on the pectoral aponeurosis presented difficulties. For placement of this suture, we can temporarily push the IPG within the pocket as medially as possible. For this purpose, it is easier to use sutures with a half-circle and long (25 mm) needle.

Figure 3: Holding up the above skin with two sutures while pushing (from the inferior entrance of the tunnel) the cervical obturator (female cadaver). 1) retroauricular incision (superior entrance of the cervical tunnel), 2) cervical tunnel, and 3) suture (non-absorbable).

Figure 4: Cervical tunnel (male cadaver). 1) secondary pocket, 2) cervical tunnel, 3) intermediate incision, 4) clavicle, and 5) incision of the main (IPG) pocket.

Landmarks and the supraorbital nerve

We identified the lateral canthus-tragus line and the line two-finger breadths above the superior orbital rim (Figure 1). Skin landmarks of the superior sagittal sinus, transverse sinuses and confluence of sinuses (torcular Herophili), are the midline at the occipital bone, the base of the mastoid process-parietomastoid suture and the inion, respectively.

Nerves of the head which could potentially suffer an injury from large pins or even small fiducials’ placement (frame-based and frameless stereotactic technique, respectively), comprise of the lesser and greater occipital nerves, the auriculotemporal nerve, zygomaticotemporal nerve, supraorbital nerve (Figure 6) and supratrochlear nerve.

Table 1 shows the results of our anatomical study about the course of the supraorbital nerve at the forehead. We measured the distance of the supraorbital foramen (where rises the nerve) from the midline (A), the distance of the nerve’s bifurcation point (branching) from the supraorbital foramen (B) and the distance of the point where the nerve crosses the line, two-finger breadths (3 cm) above the supraorbital rim (C), from the midline. We found that the right
Figure 5: Finished IPG implantation (male cadaver). 1) implanted IPG analogue at the right subclavicular area, 2) sutured subclavicular incision, and 3) main (IPG) pocket.

Table 1. Anatomical study of the supraorbital nerve at the forehead.

<table>
<thead>
<tr>
<th>Measured distances</th>
<th>Cadaver 1</th>
<th>Cadaver 2</th>
<th>Cadaver 3</th>
<th>Cadaver 4</th>
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<td>R</td>
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<tr>
<td>A (mm)</td>
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<td>35</td>
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<td>B (mm)</td>
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<tr>
<td>C (mm)</td>
<td>53, 59*</td>
<td>53</td>
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A: distance of the supraorbital foramen (where rises the nerve) from the midline, B: distance of the nerve’s bifurcation point (branching) from the supraorbital foramen, C: distance of the point where the nerve crosses the line two-finger breadths above the supraorbital rim, from the midline, R: right, L: left, *: two branches, **: three branches, -: not identifiable at the studied area.

Discussion

Lead implantation

Scalp and skull

Entry points are usually selected after proper trajectory confirmation with the stereotactic navigational software. In our cadaveric study, we proposed a method of approximation of the location of these points, which could be useful in practicing surgical technique on cadavers.

Kouyialis et al. reported the use of a single semilinear incision for bilateral implantation of DBS electrodes in the treatment of movement disorders (in a series of 12 patients), in order to avoid some of the hardware and skin related complications of this procedure. In the cadaver where we applied this technique, we observed that it allows a wider surgical field, but there is also a longer surgical incision. Moreover, the preparation of a subperiosteal pocket is technically more difficult compared to the subgaleal pocket.

Meninges and brain

The dura, arachnoid and choroid matters on each side are usually supraorbital foramen is located more laterally than the left one. Furthermore, the supraorbital nerve usually bifurcates (one to three branches) at the forehead, especially the right one.
coagulated and opened. Some teams do not open the dura and insert the tube guide by puncture of the dura, thus preventing subdural air penetration and cerebrospinal fluid (CSF) leakage. Except when the dura is not opened, either gelsoam and/or fibrin glue is placed around the cannula in the burr hole to provide a seal, thus minimising CSF loss and pneumocephalus 14.

Entry points on the cerebral cortex are chosen based on the patient’s anatomy, to provide a safe and optimal trajectory through the areas of interest. The precise entry point may be refined on the planning console such that the trajectory passes through the crown of a gyrus rather than into a sulcus. This avoids inadvertently damaging sulcal or pial vessels, which lie on the cortical surface. Any given trajectory must be altered to avoid major visualised vascular structures14.

Parieto-occipital tunnel

In manipulating the DBS lead, sharp instruments or instruments with ‘teeth’ should always be avoided since insulation may be inadvertently damaged. Likewise, when using metal instruments, care should be taken to prevent accidental crushing of the wires. The surgeon’s fingertips may be the best instruments to deal with these delicate devices14.

The subcutaneously tunnelled extender cable usually runs posterior to the patient’s ear over the mastoid process15. We have already described our technical notes regarding the retroauricular area. The connector should never be placed at the level of the neck below the mastoid, where mobility tends to cause tethering and resultant hardware failure can occur. Although a good position for the connector is the retroauricular region, when located too medially it can cause pain while sleeping supine and may come in contact with the lesser or greater occipital nerves. On the other hand, if located too laterally, it may cause discomfort while wearing glasses. Some teams place it higher on the head, at the upper part of the temporal muscle14. Another reported structure for anchoring the lead-extender connection is the occipitalis muscle13. Furthermore, regarding this part of the procedure, it is important to note the risk of a cosmetic problem (swelling of the connector). Superficial drilling of the parietal cranium area could be applied to bury the connections for a better cosmetic result.

Kouyialis et al. reported that the hair is shaved where the incision is to be carried out and also along the planned path for the extension leads, in case an intermediate incision is required1. Such an incision is also reported by the manufacturer11. We noticed that this incision significantly reduces the time of the procedure when applied at both the parieto-occipital (Figure 2) and cervical tunnels. Especially for the latter, an intermediate incision revealed to be quite helpful (Figure 4).

Pulse generator implantation

Cervical tunnel

This tunnel, starting either from the upper or lower area, should have as few curves as possible, and it should be positioned as laterally as possible to avoid accidental traumatism of the lesser branches of the jugular vein system. The length of the cadaver neck was an important factor in determining the duration of the procedure (greater for longer necks). The above mentioned intermediate incision was particularly necessary in cases with a long neck. We would also like to mention the notification by the manufacturer for slowly proceeding when approaching the IPG pocket to avoid additional trauma to the patient as resistance to tunnelling suddenly ceases11.

Sherif et al. found significantly less lead-extension related pain for a larger tip diameter of the tunnelling instrument (50 patients evaluated). A larger tunnelling diameter may cause greater extension of the elastic and collagen fibres in the subcutaneous tissue, leading to larger dilatation of the tissue tunnels. They also mentioned that for the surgical implantation procedure, the industry may wish to consider tunnelling systems with a larger tip diameter leading to more dilatation of the subcutaneous tissue tunnel2. This report seemed very interesting to us because our tunnelling ‘instruments’ were slightly larger than the original instruments.

Subclavicular implantation

Although no major branches of vessels or nerves appear in this area, in one case, we found a few remarkable branches of the thoracoepigastric vein at the lateral side of the IPG pocket. Maybe such cases should be taken into consideration by surgeons, especially in patients where such vessels serve as communication between the superior and inferior vena cava systems.

According to the manufacturer, the IPG should be placed in the pocket to assure a proper fit and then it should be removed. It should be located no more than 4 cm beneath the surface of the skin in subcutaneous tissue to allow proper programming. It should also be placed away from bony structures and with the etched identification side facing outward, away from muscle tissue to minimise pain at the IPG site. Any excess extension wire should be wrapped around the perimeter. Securing the IPG in the subcutaneous pocket is achieved using the suture holes in the connector block to secure it to the muscle fascia12. Moreover, anchoring of the generator to subcutaneous fat should be avoided since caudal migration may occur due to the weight of the IPG14.

Implanting the IPG on the right side allows possible future placement of cardiac devices on the left side12. Hence, we chose to implant the IPG preferably on the right side of our specimens.
Regardless of the location, it is useful to mark the incisions, before the final patient position, to achieve maximal symmetry and cosmetic appeal. Marking the subclavicular incision in women deserves special attention for cosmetic purposes. It may be useful to mark the incisions in the standing or sitting positions in order to best predict the final location of the incisions and generators14.

The most common location for IPG placement is the subclavicular area (typically 2 cm below the clavicle and 4 cm away from the midline). Other sites reported as appropriate for IPG placement are the subcostal area, the flank, the lumbar region and the buttocks. All of these alternate sites require the use of a longer extension lead14. Important factors that must be considered for IPG placement include the amount of the subcutaneous fat tissue, height of the patient, position of the breast in women and the general cosmetic appearance. A thin layer of subcutaneous fat should make the neurosurgeon think about positioning the IPG under the pectoral aponeurosis, therefore enhancing the possibility of hematoma14. Machado et al. reported better embedding of the IPG in the subcutaneous fat tissue. This better embedding of the IPG in a bigger layer of subcutaneous fat tissue but also due to the existence of the breast. Therefore we agree with Sherif et al. that smaller IPGs would provide less discomfort when exposed to direct tissue pressure and would result in less cosmetic deformity2. Furthermore, Machado et al. reported that the volume of a Kinetra system may impose a risk of erosion in very thin patients14.

**Landmarks and the supraorbital nerve**

Machado et al. reported that the anterior pins (of the frame) could be placed two-finger breadths above the orbital rim, taking care to avoid the supraorbital nerve14. Hence, we focused on the specific line and chose the specific nerve for further anatomical investigation. The same authors reported that the posterior pins should be located so as to avoid penetration of the cerebral venous sinuses14. Based on this notice and our anatomical notes, we suggest that the posterior pins of the frame should not be placed at the occipital midline (superior sagittal sinus), the base of the mastoid process-parietomastoid suture (transverse sinus) or the inion (confluence of sinuses).

Unfortunately, statistics on the rate of reported injury to the supraorbital nerve and the associated morbidity are extremely rare in the literature. Interpreting our results regarding the anatomical study of the supraorbital nerve, we see that the distance of the supraorbital foramen (where rises the nerve) from the midline ranges from 20 mm to 41 mm and that the nerve is divided into branches 13–27 mm far from the supraorbital foramen. Furthermore, following the line two-finger breadths above the supraorbital rim, we noticed that it crosses either the trunk (30–53 mm far from the midline) of the supraorbital nerve or its branches (38–64 mm far from the midline). These areas should be considered as risky for injuring the supraorbital nerve when placing large pins of frame-based or small fiducials of frameless stereotactic surgery. Sriki-jvilaikul and Bhidayasiri, reporting frameless stereotactic technique for DBS (9 cases experience), described the use of five fiducials, two at the front, two at the back and one at the posterior midline to cover the entire head16. The distances of the supraorbital nerve from the midline, presented in our study, could help neurosurgeons to avoid traumatizing this nerve when placing the front fiducials. The risky skin areas we mentioned above for frame pins placement are of the same value for frameless back fiducials.

Machado et al. also noticed the value of the line extending from the lateral canthus/orbital floor to the tragus (contained in our anatomical study) by reporting that the base of the frame should be placed parallel to this line, in order to parallel approximately the anterior-posterior commissure line14. We agree with these authors that care must be taken such that the edges of the frame should never be in contact with the nose or the occipital/neck area due to risk of skin erosion14.

**Considerations**

The strengths of our study lie in the fact that we designed our materials and methods after careful review of the few DBS technical reports in the literature and especially the technical manuals of the manufacturer (Medtronic). They also include step by step evaluation of the procedure and examination of variant manoeuvres (such as the semilinear incision and intermediate incisions along tunnels). Furthermore, we focused on a part of the surgical procedure (extracerebral) which is usually underestimated (compared with its intracerebral part), although the complications accompanying this part of the procedure are remarkable. We would also like to emphasise that we described an inexpensive method of practicing neurosurgical skills. The only weakness of this study was the lack of real DBS materials and instruments and the fact that we practiced the procedure on cadavers and transferred our results to real surgery. Unfortunately, this is an expected limitation considering
anatomical (cadaveric) studies. Additionally, our observations were made on a relatively restricted sample size (four cadavers). However, human cadaver models are especially beneficial because they are the closest to live surgery, although their greatest disadvantage is that they lack haemodynamic factors.

Laboratory training with human specimens provides an adequate environment for gaining both technical and anatomical expertise. Neurosurgical technique and anatomical knowledge require extensive laboratory training before these skills can be mastered. We believe that the methodology of our study could easily form a basis for a training course on the DBS surgical procedure as a basic step for residents and young neurosurgeons. The benefits, increasing acceptance and the expanding use of this method, indicate that such courses are going to be very common in the future.

Conclusion
We presented a cadaveric study of the extracerebral surgical technique of the DBS, which is a minimally invasive revolutionary neurosurgical method. This underestimated part of the procedure hides uncommon anatomical details and difficult technical points. Their knowledge can help neurosurgeons in decreasing the observed complication rates.

Summarising our principal findings, we could say that coronal and sagittal cranial sutures are difficult to identify in the elderly. During the retroauricular incision, attention should be paid to avoid injuring the occipital vessels. A small intermediate incision at the midpoint of each tunnel remarkably helps in decreasing the procedure’s duration and risks. The most difficult part of the procedure, at least in our study, was the cervical tunneling, especially its midpoint. Noticeably, beginning from its superior entrance could increase the probability of leading the driver under the fascia of the sternomastoid muscle.

Regarding the preparation of the pulse-generator pocket, it is preferable to destroy the inferior layer of the subcutaneous fat in order to avoid injury of the pectoral aponeurosis. The lateral limit of the pocket’s incision must be as vertical as possible to the cervical tunnel axis in order to avoid accidental traumatism during tunneling, and the two dimensions of the pocket have to be at least 1 cm greater than the respective dimensions of the pulse-generator. Moreover, we provided anatomical information about the supraorbital nerve and skin landmarks of the head for safer pins or fiducials’ placement (frame-based and frameless stereotactic technique, respectively).

We support the understanding that for moving one step further we should always begin by going back to the basics, and that is what we did in this study. Anatomy was, is and will continue to be, the main basis of surgery in the future.

Abbreviations list
BMI, body mass index; CSF, cerebrospinal fluid; DBS, deep brain stimulation; JP, implantable pulse-generator; PGA, polyglycolic acid.

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References
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All authors contributed to the conception, design, preparaƟƫon of the manuscript, as well as read and approved the final manuscript.

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