**Approaches and landmarks for nucleus accumbens area: a review of the literature and review-based suggestions for nucleus accumbens surgery**

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**Abstract**

**Introduction**

The paper reviews the literature regarding the existing neurosurgical techniques for approaching nucleus accumbens (NA) area and suggests new (non-stereotactic and alternative stereotactic) approaches to this nucleus as well as relative anatomical landmarks.

The literature regarding neurosurgical approaches applicable to the NA area as well as relative anatomical landmarks was reviewed.

**Discussion**

The well-established approach to the NA through the internal capsule could be used for stereotactic biopsy or aspiration. A transorbital, transnasal or an endoscopic approach through the lateral ventricle could be applied to the NA. More invasively, an inferior frontal or an approach through the frontal horn of the lateral ventricle could be applied. Stereotactic radiosurgery and inferior frontal approach could be useful for stereotactic ablation of the NA. Based on its anatomical location and relations, new potential landmarks useful in non-stereotactic surgery of this nucleus are also presented.

**Conclusion**

Apart from the approaches and landmarks that are used nowadays for approaching the NA area, there are some other potential approaches and landmarks for reaching this crucial area of the human brain.

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Using thin electrodes, the smallest areas of the brain and fibre tracts can be targeted with high accuracy; this considerably lowers the subsequent rate of side effects\(^\text{10}\). Therefore, nowadays, the term ‘NA surgery’ is almost synonymous to the term ‘NA DBS’. A trajectory through the ALIC for NA DBS is strongly supported as per the literature\(^\text{4,11,12}\). Specifically, it follows the angle of the white matter fibre tract in coronal plane so that the electrodes traverse the ALIC and terminate in the vicinity of the NA\(^\text{4,12}\). Entry point and final trajectory are planned to avoid ventricles, sulci and vessels present along the electrode path\(^\text{13}\).

Reaching the NA through the ALIC (Figure 1a–d) is the only surgical approach that is used nowadays for DBS or stereotactic ablation. The burr hole is usually placed at the frontal bone, a few millimetres anterior to the coronal suture, and after opening the meninges, the brain is usually entered at the middle frontal gyrus (where the electrode’s trajectory is planned to pass through). Approximately, the first half of the electrode’s course within the brain (after penetrating the frontal cortex) is through the white matter of the frontal lobe, whereas the second half of the course follows the ALIC till the NA.

Based on this method, stereotactic or computed tomography (CT)-guided biopsy of the NA could be performed. The involvement of this major ‘pleasure centre’ in several neurological and psychiatric disorders may potentially lead to the application of such a procedure in future. Moreover, stereotactic or CT-guided aspiration of a cystic lesion in this area could be another option. CT-guided aspiration could be the first-choice approach for treating spontaneous putaminal haemorrhage considering bleeds of ≤50 ml, while the key-hole approach may be more suitable for those with larger haematomas\(^\text{14}\). Since the NA is the area of continuity between the caudate nucleus and putamen, such a treatment is applicable to NA haemorrhage as well.

**Transorbital**

The transorbital key-hole approach to anterior communicating artery aneurysms was developed as a minimally invasive method for safe control of the anterior communicating artery complex. This approach does not necessitate resection of the gyrus rectus. The orbitocranial key-hole approach seems to be substantially better than craniotomy, although it requires additional effort and time. Technically, the orbital cortex should be gently elevated and the posterior aspect of the gyrus rectus should be separated from the optic chiasm\(^\text{15}\).

The supraorbital craniotomy allows wide intracranial exposure of the deep-seated supra- and parasellar region (where the NA lies, Figures 2a, 3a and 4a), according to the concept of...
key-hole approaches\textsuperscript{16}. The supraorbital approach, through an eyebrow incision, involves a small craniotomy flap flush to the orbital roof\textsuperscript{17}. As used for meningiomas surgery\textsuperscript{17}, it could be performed for NA surgery by introducing the endoscope through the key-hole and advancing between the frontal lobe and the floor of the anterior skull base, all the way to the NA. To get better basal view, the posterior frontal bone, sphenoid ridge or superior orbital roof could be drilled away. This allows an overview of the ipsilateral and parts of the contralateral anterior fossa\textsuperscript{17}.

The _transorbital roof_ craniotomy is a frontal craniotomy that incorporates the orbital roof and is performed via a suprabrow incision. This technique, primarily used for resection of mass lesions, provides excellent exposure to the orbit, anterior fossa and parasellar region, with little significant morbidity\textsuperscript{18}. Together with supraorbital craniotomy, there are more invasive procedures and should be considered in cases of NA area tumours only.

Following the principles of _transorbital key-hole endoscopic_ surgery, the anterior cranial fossa can be accessed through a hole at the superior orbital wall located very close to the midpoint of the superior orbital ring. After a diagonal course at the floor of the anterior fossa, the NA can be reached by penetrating the inferior hemispheric surface (Figure 2a–b), just posterior to the formation of the olfactory tract (at approximately 10 mm laterally to the midline) or medially to the initial part of this tract. Endoscopic surgery of this nucleus could be performed with this method. Attention should be paid not to traumatize the olfactory tract, optic nerve (as it emerges from the optic chiasm) and arterial branches (mainly of the recurrent artery of Heubner), which enter the anterior perforated substance. Reaching the NA through a _supraorbital or transorbital roof_ craniotomies are more invasive techniques and perhaps preferable for mass resections.

**Transnasal**

Although endonasal anatomical variations occur frequently, they rarely cause trouble in gaining access to the sellar region and therefore require experienced pituitary surgeon in practically all cases\textsuperscript{19}. _Endoscopic transphenoidal_ surgery has a clear place in the extended approach to suprasellar tumours, such as craniopharyngiomas, and is far better in managing some complications, such as cerebrospinal fluid leaks\textsuperscript{20}. Moreover, the _free-head navigation endonasal transphenoidal_ technique, which combines microscopy and endoscopy, is a safe, quick and effective approach to lesions of the sellar region. This combined approach saves time, avoids mucosal disruption, maximises the resection and shortens the patient’s hospital stay\textsuperscript{21}.

_Endonasal_ approaches achieve a direct and wide exposure of the midline cranial base anatomy. The main lateral limitations of these approaches are the optic nerves, lateral cavernous sinus, vidian nerve, internal carotid artery, abducens nerve in Dorello’s canal, jugular tubercle and hypoglossal canals\textsuperscript{22}. Given the location of the NA, these limitations would not really be an issue in NA surgery. Understanding the anatomical limits of each approach aids a surgeon in providing a full surgical armamentarium to address cranial base pathology. Three-dimensional visualisations aid in understanding the deep relationships of the densely packed, highly sensitive neural and vascular elements of the paramedian cranial base\textsuperscript{22}, where the NA is located (Figures 2a and 3a).

Following the principles of _transphenoidal endoscopic_ surgery, the anterior cranial fossa can be accessed at its posterior part, considerably close to the midline. Subsequently, the NA can be reached either through the inferior hemispheric surface (Figure 3a–c), just posterior to the formation of the olfactory tract (or lateral to the latter’s initial part), or through the internal hemispheric surface (Figure 3b–d), just anterior to the anterior commissure (AC). In both variations of this technique, the intracerebral course to the NA is only a few millimetres. While applying the first variation, attention should be paid not to traumatize the olfactory tract, optic...
nerve and arterial branches, which enter the anterior perforated substance. Regarding the second variation of the transnasal approach to the NA, special care should be taken to avoid injury to the anterior cerebral artery (anterior to the anterior communicating artery) at the internal hemispheric surface.

**Inferior frontal**

This approach, if used for NA stereotactic surgery, has the advantage that the trajectory passes through a safer path when compared with the ALIC (where so many important fibres are closely located). Other approaches used for frontal cranial base surgery include the unilateral and bilateral subfrontal (bifrontal) approaches. The frontolateral approach for olfactory groove meningiomas has been reported to be preferable because it provides quick access to the tumour with less brain exposure, while still enabling total tumour removal with a low morbidity rate and no mortality. A reported approach to symptomatic cavernous malformations deep in the anteroinferior basal ganglia (where the NA lies) is through the supracoarotid triangle, between ascending perforating arteries and through the basomedial frontal lobe. The supracoarotid–infrafrontal approach incorporates an orbitozygomatic craniotomy, wide microsurgical exposure of the supra-coarotid triangle, dissection of perforating arteries and image-guided resection through the posterior part of the medial orbital gyrus and anterior perforated substance. All these approaches seem to be too invasive to have a place in NA surgery, except for cases involving extended tumour resection.

To apply a transcortical key-hole approach, the anterior cranial fossa can be entered through a hole at the frontal bone at approximately 20 mm lateral to the midline and 15 mm superior to the eyebrow. Subsequently, the NA can be reached via a straight course within the inferior-medial part of the (ipsilateral) frontal lobe (Figure 5a–b). Stereotactic surgery (ablation) of the NA could also be applied with this method.

**Through the lateral ventricle**

The transsylvian approach (performed via a pterional craniotomy of 5 cm in diameter) or the less invasive transcortical key-hole approach can be used to enter the temporal horn of the lateral ventricle. In the latter, a 3 cm craniotomy is centred on the projection of the middle temporal gyrus. Neuronavigation is used to determine the optimal placement of a 2 cm corticotome in the middle temporal gyrus and to direct the white matter cleavage to the temporal horn of the lateral ventricle. Respectively, a frontal craniotomy centred on the projection of the middle frontal gyrus can be performed for a transcortical key-hole approach to the NA through the frontal horn of the lateral ventricle.
We consider that flexible endoscopes would be more adequate and safer for approaching the NA and also other paraventricular nuclei through the lateral ventricle.

Following the principles of interven
tricular endoscopic surgery (transcortical key-hole approach, temporal craniotomy), the endoscope is guided to the frontal horn of the lateral ventricle, after an interventricular course through its body. The NA can be reached by penetrating the floor of the horn anterior to the AC (Figure 4b). Alternatively, the ventricular system can be entered through the frontal lobe, following a straight diagonal intracerebral course within this lobe, from the middle frontal gyrus (also transcortical key-hole approach, frontal craniotomy) to the lateral aspect of the roof of the frontal horn of the lateral ventricle (Figure 4a).

**Intravascular**
A multidisciplinary approach that considers observation, microsurgery, embolization and radiosurgery, alone or in combination, is imperative to the effective management of arterio-venous malformations (AVMs) of the basal ganglia (where the NA lies) and thalamus. Malformations, lateral to the carotid bifurcation, usually receive arterial supply from the M1 segment of the middle cerebral artery or the recurrent artery of Heubner and their venous drainage to the basal vein. Such an AVM pattern is highly probable for NA area, given that the NA is usually supplied by this artery and is also placed lateral to the carotid bifurcation. A theoretical NA necrosis with interventional radiology techniques would probably necessitate a hyperselective vascular embolization.

In selected cases, intravascular approach to the NA could be considered. After careful identification of the vessels supplying blood to the NA with angiography of the internal carotid system (digital subtraction angiography or magnetic resonance imaging), a surgical approach to the NA is feasible through a transcortical or transperitoneal route. This approach is invasive and carries a higher risk of complications compared to the endoscopic approach. However, it allows direct access to the NA and its surrounding structures, which may be crucial for certain cases of AVMs or other lesions affecting the NA.

**Figure 4:** Approach to the NA through the lateral ventricle. (a) Human brain, right cerebral hemisphere, coronal section 2 mm anterior to the AC and visceral skull–posterior cranial fossa. (b) Human brain, left cerebral hemisphere, coronal section 2 mm anterior to the AC (axial section at the intercomissural level).

**Figure 5:** Inferior frontal approach to the NA. (a) Human brain, right cerebral hemisphere, coronal section 2 mm anterior to the AC and right hemi-skull, internal surface (coloured bones of the visceral skull). (b) Human brain, right cerebral hemisphere (removed frontal and parietal opercula), coronal section 2 mm anterior to the AC and skull (removed parts of the frontal and parietal bones, coloured bones of the skull).
Angiography), they can be reached by using interventional radiology techniques. Infusion of drugs to affect the NA function, chemotherapeutics for tumours in the NA area as well as materials to selectively occlude these vessels could be achieved via this method. Selective occlusion of the NA vessels could be used instead of stereotactic ablation, for embolization of regional AVMs or aneurysms and for oncological purposes.

**Radiosurgery**
In our opinion, it is only a matter of time for stereotactic radiosurgery of the NA to be applied. Ablation of this structure would probably be the easiest and most effective application of this method. By using carefully identified stereotactic coordinates, precise targeting can be achieved. Of course, conventional radiosurgery owns its rightful place in treating tumours of the NA area.

**Landmarks**

**Brain structures**
There are four alternative reference landmarks which have been reported to date for measuring Y stereotactic coordinates of the NA target area for NA DBS: the anterior border of the AC, the posterior border of the AC, the mid-commissural point and the posterior commissure (PC). Of these, the most adequate for measuring this coordinate is the anterior border of the AC, as we have previously anatomically explained. On the other hand, there is an agreement among authors regarding the reference landmarks for measuring the X and Z stereotactic coordinates, which represent the midline and AC-PC plane, respectively. Some authors use the term ‘AC-PC line’, meaning the common linear part of the AC-PC plane and the midline. This landmark allows measurements of both X and Z stereotactic coordinates.

The role of the ALIC as an anatomical landmark in NA DBS has been mentioned above. The olfactory tract and optic nerve (near the optic chiasm) are identified mainly for their specific anatomical location. The frontal horn of the lateral ventricle is easily identifiable intraoperatively as well as on CTs and magnetic resonance images. Finally, the recurrent artery of Heubner (occasionally duplicated) usually originates from the A2 segment of the anterior cerebral artery, from the anterior cerebral artery–anterior communicating artery junction, or rarely from the A1 segment. Its branches include olfactory, frontal, branches for the Sylvian fissure and branches penetrating the anterior perforated substance.

The midline and middle frontal gyrus have also been used as landmarks for stereotactic surgery of the NA. As mentioned above, the AC and middle frontal gyri can be used as anatomical landmarks for non-stereotactic NA surgery as well. Further, the olfactory tract, optic nerve (near the optic chiasm), ground and superior-lateral aspect of the lateral ventricle’s frontal horn as well as the recurrent artery of Heubner could also be used as such landmarks.

**Bony and skin structures**
The inferior orbital ring and external auditory meatus have been reported as external landmarks for a parallel to the AC–PC line placement of the DBS stereotactic frame. In ALIC DBS in the vicinity of the NA for treating Tourette’s syndrome, burr holes were reported to be placed 3.5 cm lateral to the midline. In a similar procedure for refractory obsessive–compulsive disorder, the trajectory has been reported to lead (in sagittal plane) to a burr hole just anterior to the coronal suture. In addition, intraoperative and postoperative X-ray as well as cranial CT have been used to verify the correct positioning of the DBS electrodes. Finally, according to a few reports of stereotactic ablation of the human NA, the incision on the scalp skin is placed 9–11 cm above the eyebrows and 2.5 cm lateral to the midline. As mentioned above, the midline, superior orbital ring and eyebrow can be used as anatomical landmarks for non-stereotactic NA surgery.

**Conclusion**
The well-established approach to the NA through the ALIC could be used for stereotactic biopsy or aspiration. Considering the possibility of endoscopic surgery of this area, we suggest that a transorbital, transnasal or an endoscopic approach through the lateral ventricle could be used (Figure 6). Considering the possibility of more invasive surgery in this area, we suggest that an inferior frontal or an approach through the frontal horn of the lateral ventricle could be applied. In selected cases, intravascular intervention and radiosurgery could also have a role. Further, we believe that stereotactic radiosurgery as well as an inferior frontal approach could be useful in NA stereotactic ablation.

Except for the nowadays used cerebral, bony and skin anatomical landmarks for NA stereotactic surgery, there are other potential landmarks useful in non-stereotactic (endoscopic or non-endoscopic) surgery, which are based on its anatomical location and relations.

**Abbreviations list**

AC, anterior commissure; ALIC, anterior limb of the internal capsule; AVM, arteriovenous malformation; CT, computed tomography; DBS, deep brain stimulation; NA, nucleus accumbens; PC, posterior commissure.

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Critical review

References

Figure 6: Schematic drawing of the approaches to the NA (human brain, left cerebral hemisphere, coronal section 2 mm anterior to the AC and visceral skull–skull base). 1. Through the ALIC; 2. Transorbital approach; 3. Transnasal approaches; 4. Inferior frontal approach; 5. Through the lateral ventricle (entered for example from the temporal horn); 6. Head of the caudate nucleus; 7. ALIC; 8. Putamen; 9. Insula; 10. Middle frontal gyrus; 11. Internal hemispheric surface; 12. Olfactory groove; 13. Superior orbital rim. Trajectories are lightened when passing through structures where they are superimposed on.
Critical review