Comparative Analysis of Extensions of Transbasal Approaches: Effect on Access to Midline and Paramedian Structures

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ABSTRACT

We sought to quantitate the effect of extensions of transbasal approaches (TBAs) on midline and paramedian targets of the cranial base. Eight silicone-injected cadaveric heads were dissected with extensions of TBA level I removal of the orbital bar. Objective measures were the comparisons of the accessibility of midline and paramedian targets with progressive dissections by level II detachment of the medial canthal ligaments and removal of the nasal bone and by level III removal of the lateral orbital walls with lateral orbital retraction. Mean areas of freedom increased for most targets with progressive bone removal. For midline targets, the most effective freedom increment was at the pituitary gland (level II: 28.8%, $p = 0.05$; level III: 107.1%, $p < 0.001$). For paramedian targets, the best freedom increment was for the foramen rotundum (level II: 56.4%; level III: 134.5%, all $p < 0.001$). Extensions of the TBA can increase the surgical corridor to midline and paramedian structures, especially for pituitary and maxillary regions. Level II exposure offers no clear benefit for most targets except the foramen rotundum. With level III exposure, all targets are effectively exposed compared with levels I and II.

KEYWORDS: Clivus, cranial base surgery, craniofacial resection, quantitative analysis, transbasal approach

The basic transbasal approach (TBA), conceptualized as a frontal midline approach, was popularized by Tessier et al¹ and Derome.^{2,3} Similar surgical techniques were later described under

names such as the extensive TBA,^{4,5} extended frontal approach,⁶ extended TBA,^{7,8} subcranial approach,^{9,10} median subfrontal TBA,¹¹ frontal sinus approach,^{12,13} telecanthal approach,¹⁴ and radical

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TBA.¹⁵ However, we believe that these variants should be considered as extensions of the TBA.

The possible anatomic target areas reached by the TBA are the anterior cranial fossa, orbit, nasal cavity, paranasal sinuses, pterygopalatine fossa, pituitary fossa, and clivus. The lateral limits of exposure are the optic nerves, intracavernous carotid arteries, and hypoglossal canals. Despite these anatomic limitations, many extensive skull base lesions can be removed successfully through the TBA.^{4,6,9,11,14–26}

The most obvious disadvantages associated with the TBA are the risks of cerebrospinal fluid (CSF) leakage and infection. Extending the approach may increase the potential for additional complications. The goal of this study was to define an optimal surgical opening directed toward a target with the most freedom to access a specific pathology. Few comparisons of the various subtypes of the TBA have been reported.²⁷ We analyzed the critical anatomic steps in creating subtype extensions of the TBA to quantitate the surgical advantages and disadvantages of each for providing access to midline and paramedian basal structures.

MATERIALS AND METHODS

Description of Surgical Extension

The surgical steps started with a standard TBA (level 0).³ The bicoronal scalp incision was elevated in the subperiosteal plane approaching the supra-orbital rim. The pericranium was usually preserved for reconstruction. The bifrontal craniotomy was created as the first bone flap close to the frontal base. Systematic extensions of the TBA have been described elsewhere.^{28,29} Similar techniques can be categorized as discussed below.

LEVEL I TBA^{5,6,8}

In a level I TBA (Fig. 1A), extradural bone work was performed by detaching the basal frontal dura from the anterior cranial fossa. The olfactory appa-

ratus was usually detached from the cribriform plate to reach deep lesions. The supraorbital and supratrochlear neurovascular complexes can be released safely. The periorbita, including the trochlea, was detached carefully from the bone. The second bone flap (fronto-orbital bar) located on the supraorbital bar was then removed with a reciprocating saw. The inferior limit of this resection was the frontonasal suture medially and the frontozygomatic sutures laterally. The attachments of the medial canthal ligaments were preserved bilaterally. Superiorly, the orbital roof can be cut as far as and close to the orbital apex. Depending on the surgical target, this cut can cross the midline just anterior or posterior to the cribriform plate.

LEVEL II TBA^{9,11,23}

In a level II TBA (Fig. 1B), the medial canthal ligaments were detached bilaterally to prepare for the caudal bony extension. The second bone flap, the frontonasal-orbital osteotomy, was modified from the level I TBA by extending the nasal cuts on both sides to the piriform aperture inferiorly. Injury to the nasolacrimal duct must be avoided. Optionally, cuts can be made around the cribriform plate to preserve olfaction.³⁰

LEVEL III TBA^{14,15}

In a level III TBA (Fig. 1C), the frontal process of the zygomatic bone and lateral orbital walls were included bilaterally in the second bone flap. The temporal base dura need not be violated. Removal of the lateral orbital walls improved mobilization of the orbits. The lateral orbit was retracted laterally to widen the exposure. Strategies for preserving olfaction can also be incorporated.

Dissection Preparation

Eight adult, silicone-injected cadaveric heads were used to perform the three staged extensions of the TBA as described above. Predissection computed tomography images were obtained to view the surgical trajectory with neuronavigation. The head

Figure 1 Illustrations showing extensions of a transbasal approach (TBA). (A) Level I TBA. (B) Level II TBA. (C) Level III TBA. (Used with permission from Barrow Neurological Institute.)

was rigidly fixed with a Mayfield head holder. Dissections were performed grossly and under the magnification of an operating microscope.

All heads first underwent a level I TBA dissection with the olfactory preservation technique. The frontobasal dura, including the preserved olfactory apparatus, was dissected free from the anterior cranial fossa. A 2-cm tip retractor was applied on the midline frontal base covering the entire olfactory cuffs and maintained with minimal retraction.

The ethmoid and sphenoid sinuses were removed widely, exposing the upper nasal cavity. The posterior nasal septum was partially removed. The posterior portion of the superomedial orbital wall was drilled and removed to expose the orbital apices and optic nerves. The pituitary gland was exposed in the midline. The cavernous sinus with the intracavernous carotid arteries constituted the lateral limits of exposure at the level of the middle fossa. The dissection continued caudally toward the clivus. The pharyngobasilar fascia was kept intact by pushing anteriorly to obtain an unobscured corridor along the clivus. The foramen magnum and hypoglossal canals were clearly exposed in the deepest part of the clivus. The middle turbinates

were removed bilaterally to gain entry to the maxillary sinuses. The posterosuperior maxillary walls were removed to expose the pterygopalatine fossae. At this point in the dissection, the pterygopalatine ganglion, foramen rotundum, vidian canal, and infraorbital nerve were identified on each side.

All deep targets of interest could be identified through this level I TBA dissection. The midline targets included (1) the anterior foramen magnum, (2) the most inferior portion of the pituitary gland, and (3) the basal portion of the frontal lobe defining a point 3 cm from the tip of the retractor. The paramedian targets were the hypoglossal canal and foramen rotundum.

Statistical Analysis

After a head was fixed in the clamp, registered predissection images and a navigating probe (Stealth TREON Plus; Medtronic, Louisville, CO) were used to obtain Cartesian coordinate points.

The area of freedom represented the working area available for manipulating an instrument at deep target points. Four surface points were selected

Figure 2 (A) Dissection showing the area of freedom (green area) for the pituitary target in a level I transbasal approach. The tip of a straight probe is on the pituitary gland. The probe is moved circumferentially approaching the lower limit of the left orbit (E1), the upper limit of the left orbit (E2), the upper limit of the right orbit (E3), and the lower limit of the right orbit (E4). The yellow arrow on the retractor represents the basal frontal target. (B) Calculation model (r , radius: 20 cm probe). (Used with permission from Barrow Neurological Institute.)

to be related to each deep point. The surface points were E1, the lower limit of the left orbit; E2, the upper limit of the left orbit; E3, the upper limit of the right orbit; and E4, the lower limit of the right orbit. While one end of the 20-cm straight probe rested on the deep point, the other end successively approached each superficial point. The coordinates for calculating the area of freedom were collected at the free end of the probe while it was moved circumferentially from E1 to E4 (Fig. 2). The freedom area for the space between the orbit and retracted brain was intentionally excluded in this calculation. The length of the infraorbital nerve accessible from the foramen rotundum was acquired to evaluate the degree of antral exposure at each step of the TBA.

After the data were acquired for level I, more soft tissue was released and more nasal bone was removed to create a level II TBA. This dissection was performed without changing the position of the retractor. Data acquisition was repeated in the same manner for level II and level III.

All data were retrieved and then analyzed using Spherical Area program (Bitwise Ideas Inc., Fredericton, NB, Canada). The three steps of the TBA were compared by repeated measures analysis of variance followed by pairwise comparison with Holm-Sidak correction. All results were presented as mean $\pm$ standard deviations or as percentages. In all cases, a *p* value less than 0.05 was considered significant.

RESULTS

After the level I TBA was completed and the brain was retracted, the mean distance between the retractor and nasion in all specimens was 42.4 ± 6.2 mm. All the deep targets of interest could be explored through a level I TBA. For most targets, the mean area of freedom increased when dissection progressed from a level I to a level III TBA (Table 1). For most deep points, working space did not increase significantly between a level I and a level II TBA, except when the foramen rotundum was the target. A level III TBA increased the freedom area for all targets. Increasing bone removal from level I to level III TBA increased freedom the most as observed when the pituitary was the target in the midline and the foramen rotundum was the paramedian target (Table 2).

The infraorbital nerve could be followed a longer distance from the foramen rotundum when progressing from a level I to a level III TBA (level I, 12.7 ± 1.8 mm; level II, 14.9 ± 2.5 mm; level III, 23.1 ± 2.5 mm; all pairwise comparisons, *p* < 0.01). However, exploration of the maxillary roof lateral to the infraorbital nerve was difficult at all three levels. The mean interorbital distance between the medial orbits at the lateral retraction point for level I and level III increased from 26.1 ± 3.3 mm to 46.0 ± 2.6 mm (mean difference, 19.9 ± 2.5 mm).

Table 1 Mean Area of Freedom for Each Deep Target

Targets	<i>n</i>	Mean Area of Freedom (mm ²)		
		Level I TBA	Level II TBA	Level III TBA
Foramen magnum	8	2322.6 $\pm$ 1002.9	2925.8 $\pm$ 667.5	4203.0 $\pm$ 1048.8*
Pituitary gland	8	3982.0 $\pm$ 1222.4	5130.4 $\pm$ 2030.8	8245.3 $\pm$ 1805.3*
Basal frontal lobe	8	5194.0 $\pm$ 2073.3	4169.9 $\pm$ 2253.5	8788.7 $\pm$ 5649.4*
Hypoglossal canal	16	1522.0 $\pm$ 786.3	1880.6 $\pm$ 581.8	2348.1 $\pm$ 746.3*
Foramen rotundum	16	3844.1 $\pm$ 1410.2	6011.5 $\pm$ 1743.8†	9015.5 $\pm$ 2936.3*

*Significance found in pairwise comparison between level I and level III TBA and between level II and level III TBA. Adjusted *p* by step-down Holm-Sidak correction <0.05.

†Significance found in pairwise comparison between level I and level II TBA. Adjusted *p* by step-down Holm-Sidak correction <0.05. TBA, transbasal approach.

Table 2 Percent Increment in Mean Freedom Area

Targets	n	Mean Freedom Area Increment (%)		
		Level I to II TBA	Level II to III TBA	Level I to III TBA
Foramen magnum	8	26.0	43.7*	81.0*
Pituitary gland	8	28.8	60.7*	107.1*
Basal frontal lobe	8	-19.7	110.8*	69.2*
Hypoglossal canal	16	23.6	24.9*	54.3*
Foramen rotundum	16	56.4*	50.0*	134.5*

*Significant increment as shown in Table 1.
TBA, transbasal approach.

DISCUSSION

The TBA is one of the most valuable standard anterior approaches to the skull base. The widely available space from air sinuses and the kyphotic angle of the brain are two factors that favor this approach for appropriate regional pathology. Both intra- and extradural lesions, including craniofacial trauma, infection-related processes, and tumors, can be accessed through the TBA. Extensions of the TBA widen the surgical window while expanding the surgical corridor with relatively little brain retraction. These extensions have slowly obviated the traditional two-stage craniofacial resections that require additional facial incision and bone work.^{17,19,23,25,31} As our results show, progressive bone removal improves exposure of each deep target to a variable degree. We categorized the targets into the four groups as follows.

Posterior Fossa Level: Anterior Foramen Magnum and Hypoglossal Canal Targets

As predicted, this region is the deepest within the approach. Hence, it is associated with the least area of freedom. Because of their extreme angles, paramedian lesions are more difficult to deal with than midline lesions. The obstruction is caused by bilateral intracavernous carotid arteries in the middle fossa and in the pharyngobasilar fascia anteriorly. Increasing the caudal vertical access, as in the level II TBA, does not effectively increase the area of

freedom. Based on our observations, this situation can be explained by the difficulty of accessing the posterior fossa when the caudal trajectory is increased. The preserved pharyngobasilar fascia is a major limitation. Most of the accessible trajectories are from a rostral exposure (Fig. 3). A better strategy for dealing with lesions at this level incorporates gravitational retraction to mobilize the frontal lobe away from the cranial base. Widening horizontal access with a progression to level III TBA may be another helpful option.

Middle Fossa Level: Pituitary Target

From extensions of the TBA, this region is at the center of the optimal trajectory. Even in our study, a level II TBA provided no significant benefit compared with a level I TBA in terms of the mean area of freedom. This progression only increases the area of freedom for midline targets (28.8%, $p = 0.05$; Figs. 4 and 2A). The progression from a level I to a level III TBA, however, provides the largest increment in freedom (107.1%, $p < 0.001$) for midline targets. Nonetheless, safe access to the posterior clinoid process is impossible because the pituitary gland obstructs the view.

Anterior Fossa Level: Basal Frontal Target

A basal frontal target is the most accessible among our midline targets because it is closest to the

Figure 3 (A) Dissection showing a level II transbasal approach when the anterior foramen magnum is the target. (B) Navigation capture. ICA, internal carotid artery; P. fossa, posterior fossa. (Used with permission from Barrow Neurological Institute.)

surface and enjoys the best trajectory, even with a level I dissection. Increasing the lower bone window as in a level II TBA should markedly increase accessibility because the angle of approach is perpendicular to the frontal base. However, the bulky soft tissue of the scalp flap may restrict freedom (Fig. 5). The insignificant decrease in the area of freedom (-19.7% , $p=0.48$) reflects a balance between both of the above factors. With this vertical limit, improvement in the horizontal view through a level III TBA can increase the area of freedom

significantly, providing the largest such area among the midline targets.

Maxillary Sinus and Pterygopalatine Fossa Region: Foramen Rotundum Target, Infraorbital Nerve

This region is located near the anterior paramedian portion of the clivus. The trajectory may not differ much from that to posterior fossa targets. However,

Figure 4 (A) Dissection showing a level II transbasal approach when the pituitary is the target. (B) Navigation capture showing the nasal cuts that improve access to the pituitary target. ICA, internal carotid artery. (Used with permission from Barrow Neurological Institute.)

Figure 5 Dissections showing the obstruction of the scalp flap on a basal frontal target. (A) Level I transbasal approach (TBA). (B) Level II TBA. ICA, internal carotid artery. (Used with permission from Barrow Neurological Institute.)

the corridor is not limited by the intracavernous carotid arteries and pharyngobasilar fascia. The bulk of a scalp flap is less obstructive in this region. The effect of a level II TBA dissection is significantly

(56.4%, $p < 0.001$) different from its effect on previous regions. Progressing to a level III TBA dissection improves the area of freedom and provides the largest area among all targets. Mobilizing the

Figure 6 Dissections show exposure into the left maxillary sinus and pterygopalatine fossa. The infraorbital nerve is explored progressively. (A) Level I transbasal approach (TBA). (B) Level II TBA. (C) Level III TBA. ION, infraorbital nerve; IMA, internal maxillary artery; Pter. GG., pterygopalatine ganglion; ROT, foramen rotundum. (Used with permission from Barrow Neurological Institute.)

orbit laterally provides an adequate view to the pterygopalatine fossa and maxillary sinus located directly underneath the orbit. Consequently, obstruction from the contralateral orbit is decreased. The result is a lower tangential view along the maxillary roof that allows the infraorbital nerve to be followed for a longer distance compared with level I and II exposures (Fig. 6). This maneuver provides a better exposure of the maxillary roof, which is one of the most difficult anatomic targets to reach from the TBA.^{17,32}

SURGICAL VARIATIONS

Subcranial Approach

As described by Raveh et al, the subcranial approach was first developed for the treatment of craniofacial fracture.¹⁰ It was then adopted for the treatment of skull base tumors.^{9,24} The approach was developed to minimize exposure through craniofacial resections.³³ The primary bone flap is located in the midline region on the limited frontonasal-orbital bone flap. A separate frontal craniotomy, as used in a standard TBA (level 0 TBA), is not required. Extension of the frontal bone cut is tailored to the size of the lesion.

The primary surgical benefit of the subcranial approach is comparable to that provided by the level II TBA. In our opinion, it offers an excellent strategy to decrease manipulation of the frontal bone and to decrease operative time while providing an effective surgical window to the anterior cranial fossa and paranasal air sinuses. Nonetheless, the benefit of frontal lobe retraction is not as great with a subcranial approach as it is with the level II TBA. At the level of the posterior fossa, deep lesions that require a steep angle of approach may not be explored safely, and the surgical angle for treatment of frontal base lesions cannot be improved. For paramedian lesions associated with the orbit or maxillary sinus, an extreme tangential

trajectory is required. The lateral extent of the craniotomy should be planned to ensure its adequacy.

Based on our experience, creating a bifrontal craniotomy just lateral to the linea temporalis does not significantly increase complications. With the assistance of gravity and careful detachment of the dura of the frontal base, the frontal lobes easily fall away from the anterior cranial fossa without excessive manipulation. The working space can be widened with either a level II or level III TBA. Local excessive retraction on the basal frontal lobes through a limited opening to access a deep target, which can occur in the subcranial approach, can be avoided with a level II TBA.

How Far Does the Nasal Bone Need to Be Cut?

With a level I TBA, some surgeons may extend the nasal bone cut below the frontonasal suture at the level of medial canthal ligaments.³⁴ Doing so increases vertical access. However, the medial canthal ligaments near the cutting site should be preserved meticulously. When progressing to level II TBA, the medial canthal ligaments are usually detached with a low nasal cut.^{9,19,28,31,35,36} However, the detachment has not been achieved in other reports.^{23,25} The lower margin of the nasal cut for a level II TBA also varies. In our study and elsewhere, the piriform aperture was incised.^{9,11,28,35} Others preserve 2 to 10 mm of the distal nasal bone to prevent collapse of the nasal valve.^{14,25,36}

Even with an extensive nasal cut, obstruction from the scalp flap remains. Fujitsu et al¹⁴ overcame the limitations caused by soft tissue obstruction by partially splitting the scalp flap in the midline. However, we did not observe that effect clearly in our cadaveric specimens. Extending the nasal cut to the piriform aperture and complete removal of the nasal frame did not improve exposure except when the maxillary region was approached. Therefore, leaving the distal nasal bone and a cartilage cuff is a viable option.

Preservation of Olfaction

Preservation of the sense of smell is a concern for the entire spectrum of TBAs.³⁷ The olfactory apparatus is often destroyed by disease itself, or its loss is accepted as a necessary consequence of the operative approach. However, when olfaction is intact preoperatively and the olfactory nerves are not involved with the pathology, an extradural technique, as described by Spetzler et al,³⁰ can preserve the sense of smell. Functional olfaction has regained satisfactory levels within 4 to 8 weeks.^{22,30,35}

With gravity-assisted retraction of the frontal lobe, the surgeon has adequate space to perform circumferential osteotomies of the cribriform plate. A critical step is the horizontal incision of the nasal mucosa to mobilize the extradural olfactory unit. The optimal length of the mucosal cuffs is debated.³⁸ Based on clinical results with attempts to preserve olfaction, the nasal mucosa should be at least 5 to 10 mm long.^{27,35}

We applied this technique with the level I TBA. From a superior exposure, the nasal septum can be cut deeply below the cribriform plate to free the cribriform plate and mucosa together. However, with the nasal bone intact in a level I approach, we found it difficult to tailor an adequate nasal mucosal cuff. This procedure may be even more difficult during a procedure on a live patient.¹⁸

Preserving the mucosal cuff limits the vertical working space. Direct and excessive retraction on the olfactory unit should be avoided. However, we placed the retractor covering the olfactory unit to demonstrate the basal frontal target. Inadvertent retraction may damage olfaction or contuse the base of the frontal lobe from the spike of the crista galli. Reconstruction is another difficulty because the dura can be disrupted by either the exposure or pathology. The reconstruction technique must be meticulous to recreate a dural barrier while maintaining satisfactory olfactory inflow.³⁵ Therefore, it is easier to incorporate the olfactory preservation technique when performing at least a level II TBA because the nasal mucosa can be cut from the additional inferior angle afforded by the level II

exposure. With a level III exposure, olfaction can typically be preserved.¹⁵

CLASSIFICATION AND SURGICAL SELECTION

Based on the extent of bone removal, Raso and Gusmao³⁹ classified the TBA into three types that differ from our definitions: a level I bifrontal osteotomy, a level II (level I + naso-orbital osteotomy), and a level III (level II + olfactory preservation). As in our previous reports, we considered potential, associated morbidity to subdivide variations of the TBA.^{28,29,40} Within our schema, olfactory preservation is reserved as an optional preference.

Complications associated with the TBA vary. Their relative risks must be balanced with the anatomic opportunities provided by the extensions of the TBA. Such risks include CSF leakage, infections, tension pneumocephalus, frontal lobe injuries, cranial nerve injuries, subdural hygromas, and seizures.

In a level I TBA, the bilateral orbital bars are removed. This procedure is usually associated with relatively low rates of morbidity (e.g., comparable to performing a unilateral orbitozygomatic approach). However, the risks of infection and CSF leakage associated with entering the sinonasal cavity are increased with a level I TBA. Most of the midline and paramedian subcranial structures can be exposed adequately. With the assistance of gravity retraction, lesions extending into the posterior fossa can be accessed through an appropriate trajectory and may not require larger openings. Olfactory preservation is difficult.

A level II TBA increases caudal vertical exposure. Dividing the medial canthal ligaments can also widen the interorbital space slightly. Complications associated with a lower nasal cut can be predicted (e.g., injury to the lacrimal drainage system, incorrect reattachment of the fronto-nasal bone flap or medial canthal ligaments). The

area of freedom improves for certain structures in the middle fossa and maxillary regions. Regardless of how insignificant the improvement may be in most of the measured areas, it still provides the most valuable trajectory to these specific targets (Fig. 4).

In a level III TBA, the lateral orbital walls are removed. The orbits can safely be retracted manually. The distance of orbital retraction in a cadaveric study does not correspond to a real-life setting. To prevent injury to the optic nerve, retraction force should be applied with caution. A level III TBA provides extra horizontal room after the maximum vertical access afforded by level II has been obtained. The widest freedom can be obtained for all targets. This level of approach should be selected when pathologies reach the extreme margins of the exposure afforded by a TBA or when lesions require en bloc removal or extensive resection to advance into the maxillary sinus. Olfactory preservation techniques can easily be incorporated.

In difficult cases, other skull base techniques via transfacial, lateral, or posterior approaches should be incorporated to maximize the surgical exposure. As always, the goal of resection should be customized to the appropriate approach.

Some minimally invasive variants of a level I TBA have been designed for specific targets.¹² With selective adaptation, the potential applications of these approaches could be expanded.^{13,41} For instance, using this approach, the midline subcranial areas can be better explored with endoscopic assistance, obviating the need for a larger craniotomy.³⁴ These techniques should be considered on a case-by-case basis. However, to some degree, surgical freedom and paramedian exposure are limited by the exposure common to all level I-type approaches.

STUDY LIMITATIONS

In all cadaveric studies, the tissue is fixed. Therefore, retraction parameters cannot simulate real

surgical situations exactly. Furthermore, surgical exposures may vary. Nonetheless, the surgical laboratory experience with cadaveric human anatomy closely parallels the operating room experience. Cadaveric dissections permit near lifelike recreations of surgical situations and permit quantitative analysis of the anatomic barriers and corridors encountered during live surgery. Therefore, such studies may help in the selection of surgical approaches.

CONCLUSIONS

Extensions of the TBA provide various benefits in terms of accessing specific targets. With a level I TBA, most of the median and paramedian subcranial structures can be explored. The level II exposure slightly expands the vertical working space. A level III TBA increases the horizontal working space and maximizes the exposure. These findings support the widespread clinical use of a level I TBA. A level II TBA can be customized through the various described techniques to the demands of specific surgical lesions. With a level III TBA, most extensive lesions involving midline and paramedian subcranial structures can be resected with the highest degree of maneuverability.

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