IN VASCULAR NEUROSURGERY, the pterional approach has been used primarily for the treatment of a wide variety of diseases (cavernous angiomas, arteriovenous malformations, etc.), and it is used to take advantage of naturally occurring planes and spaces to expose the major structures of the circle of Willis. It provides access to the major part of the anterior circulation aneurysms and those occurring in the upper and most proximal part of the posterior circulation. Conversely, there has been an increasing interest in the so-called minimally invasive procedures or keyhole approaches to treating cerebral aneurysms in specific locations. In this work, we describe a novel keyhole approach that was conceived to achieve the angle of vision and advantages of the classic pterional approach. This surgical approach is based on the anatomic location of the sphenoid ridge and its relationship with the sylvian fissure and basal cisterns. The initial incision is made over the hairline behind the external border of the eye on the side selected. A skin and muscular flap is reflected anteriorly, and a small 3 cm craniotomy is completed around the external landmarks of the sphenoid ridge. Further extradural drilling is completed down to the anterior clinoid process. The dura is opened in a semilunar manner, and the sylvian fissure is opened completely to reach the sylvian and basal cisterns. Thereafter, the aneurysm is dissected and clipped according to the standard microtechnique of the neurosurgeon. A step-by-step description of the approach is offered in this work to facilitate a clear understanding of it. We recommend this approach for treatment of aneurysms arising at the anterior part of the circle of Willis. It has the advantages of less operative time, fewer days of hospitalization, and similar morbidity and mortality compared with the standard pterional craniotomy (5.7% on our service for nongiant ruptured aneurysms).

KEY WORDS: Cerebral aneurysm, Cerebrovascular surgery, Keyhole approach, Pterional approach, Sphenoid ridge, Surgical anatomy
designed to minimize the exposure and handling of cerebral tissue without compromising the surgical results and the view of vascular and tumoral lesions (12–15, 19, 32–34, 44). Taking into account that the pterional approach is probably the most common approach in neurosurgery, we developed the sphenoid ridge approach as the keyhole concept of the standard pterional craniotomy. This approach is based on a well-planned small craniotomy, extensive bone drilling of the sphenoid ridge, and wide exposure and opening of the sylvian fissure and basal cisterns to reach aneurysms at the anterior part of the circle of Willis. In this work, we describe the anatomic and surgical basis of this approach.

**PATIENTS AND METHODS**

During the period from May 2000 to July 2003, 380 patients with cerebral aneurysms were operated on at the Division of Neurosurgery of the National Institute of Neurology and Neurosurgery “Manuel Velasco Suarez” and the National Institute of Medical Sciences “Salvador Zubiran,” Mexico City. Of the total patients, 132 were operated on by the senior author (EN), and 85 patients harboring 98 aneurysms were selected for a keyhole sphenoid ridge approach (Table 1). The surgical technique used in this group is reported here. The patients were selected according to the position of the aneurysm in the circle of Willis, neurological grade on admission, and the possible existence of associated pathological conditions such as cerebral hematoma, severe edema, angiographic vasospasm, or hydrocephalus. Only patients without associated pathological conditions were selected, as well as those with neurological Grade 0–III of the Hunt and Kosnik classification (Table 2). The remaining 47 patients did not fulfill the above criteria and were operated on via another approach according to the characteristics of the aneurysms.

**TABLE 1. Location of the aneurysms**

<table>
<thead>
<tr>
<th>Location</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paraclinoid-ICA</td>
<td>9.</td>
</tr>
<tr>
<td>Dorsal type</td>
<td>5.</td>
</tr>
<tr>
<td>Superior hypophyseal</td>
<td>3.</td>
</tr>
<tr>
<td>Ophthalmic</td>
<td>1.</td>
</tr>
<tr>
<td>ICA-PComA</td>
<td>25.</td>
</tr>
<tr>
<td>ICA-AChor</td>
<td>5.</td>
</tr>
<tr>
<td>ICA-bifurcation</td>
<td>7.</td>
</tr>
<tr>
<td>Middle cerebral artery</td>
<td>37.</td>
</tr>
<tr>
<td>Anterior communicating artery</td>
<td>15.</td>
</tr>
</tbody>
</table>

*ICA, internal carotid artery; PComA, posterior communicating artery segment; AChor, anterior choroidal artery segment.

**SURGICAL PROCEDURE**
(see video at web site)

To clarify the anatomic concepts of this approach, we divided the surgical steps as follows.

**Positioning of the Patient**

The patient is positioned supine with the head elevated 10 to 15 degrees to ensure that the final position of the head is above the level of the heart. The neck is maximally extended to increase the contribution of gravity and venous drainage. The head is rotated 45 degrees away from the side of the craniotomy; however, the rotation of the head may vary according to the aneurysm location from 15 to 20 degrees for anterior communicating artery aneurysms to 60 degrees to some MCA aneurysms. The head is placed in a horseshoe headrest or a three-point fixation device, such as the Mayfield-Kees head holder.

**Surgical Planning**

The main sites to be identified on the scalp before application of the surgical drapes are 1) the frontozygomatic point, 2) the sylvian line, and 3) the pterion. The frontozygomatic point is located on the orbital rim 2.5 cm above the level at which the upper edge of the zygomatic arch joins the orbital rim and just below the junction of the lateral and superior margins of the orbital rim. The sylvian fissure is located along a line that extends backward from the frontozygomatic point across the lateral surface of the head to the three-quarter point (75% of the distance between the nasion and the inion on the midline) (29). The pterion, which represents the site on the external surface of the cranium approximating the lateral end of the sphenoid ridge, is located 3 cm behind the frontozygomatic point, on the path of the sylvian fissure line and in close proximity to the greater sphenoid wing.

**TABLE 2. Comparison between the neurological grade on admission (Hunt and Kosnik) and the Glasgow Outcome Scale Score**

<table>
<thead>
<tr>
<th>H-K grade</th>
<th>Glasgow Outcome Scale score</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
<td>1 1</td>
</tr>
<tr>
<td>1</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>77</td>
<td>5 2</td>
</tr>
</tbody>
</table>

*H-K, Hunt and Kosnik.
relationship with the hairline (Figs. 1 and 2). Even when this area shows anatomic variations from one individual to another, there is a bony depression following the main axis of the sylvian line. If we press firmly over the temporal area beneath the temporal muscle, this depression is easily detected. If we follow this depression caudally until it crosses the hairline on the skin surface, we are actually following the course of the sphenoid ridge up to the pterion. Thus, the sphenoid ridge is closely related to the vallecula of the sylvian fissure and to the MCA.

Incision

A 4- to 5-cm incision is planned at the level of the hairline, centered at the estimated location of the end of the sphenoid ridge (Fig. 2). After the extension of the incision has been planned, the hair is strip-shaved 1 cm behind the hairline to avoid hair extending into the surgical field. After the surgical area has been wrapped, the skin is infiltrated with xylocaine with 2% epinephrine to avoid excessive bleeding from the superficial layers. The skin is incised over the planned line, and skin clips are not used to stop bleeding; rather, the bleeding points are cauterized with a bipolar coagulator of Malis to avoid a bulky skin flap. If it is planned to preserve the superficial temporal artery, we should locate the course of the artery before the incision is made, because, as a result of anatomic variations, the artery may run rostral or caudal at the border of the incision in the areolar tissue under the skin. In addition, the skin is dissected from the superficial temporal fascia and retracted with silk stitches or fishhooks.

Dissection of the Superficial Layers and Temporalis Muscle

After the skin and subcutaneous tissue are dissected, the superficial temporal fascia and muscle are opened in the same
direction as the skin incision, following the natural direction of the muscle fibers (Fig. 2). At this point, it is not necessary to take care of the frontal branch of the facial nerve that runs rostral to the point of incision. To date, we have not had any patient with a postoperative lesion of the nerve. The bone is exposed after subperiosteal dissection, and the hooks are repositioned to include the skin and muscular layers. The external representation of the end of the sphenoid ridge is identified. Usually, at this point, the location of the sphenoid ridge is felt by touch as a small depression over the bone surface, pointing up the separation between the frontal and temporal lobes of the brain.

**Craniotomy**

A single burr hole is made with a craniotome placed at the most caudal aspect of the surgical exposure and centered over the bony depression representing the sphenoid ridge on the external surface of the cranium (Figs. 1C and 2C). After completing the burr hole, one can see the depression of the dura covering the sylvian fissure and the spike-shaped bone pointing up the sphenoid ridge on the inner part of the cranium. Sometimes the burr hole is deviated slightly over the frontal or temporal area, primarily if the sphenoid ridge is very prominent. In such a case, we can extend the opening with a high-speed drill or bone rongeurs to the opposite side to completely expose the dural folding between the frontal and temporal areas. Thereafter, a dural dissector is used to separate the dura mater from the bone, especially in elderly patients, to avoid the possibility of a dural tearing with the craniotome. The bone cut starts superiorly up to 1 cm before the temporal line, then curving gradually anteriorly and inferiorly. At this point, a large sphenoid ridge is sometimes encountered, and further inferior cutting with the craniotome is blocked. In this case, a second cut is made from the burr hole to the inferior edge of the sphenoid wing, symmetrical with the upper cut. In this way, an oval-shape craniotomy approximately 2 × 2.5 cm in diameter is completed (Fig. 2). Sometimes, it is necessary to use a small bone chisel to complete the cut line over the sphenoid ridge when this structure is prominent to avoid bone fragmentation. After the bone flap is elevated, the dura is freed in an epidural manner away from the orbital roof and the sphenoid wing. By use of a high-speed drill with a diamond burr, the lateral part of the sphenoid wing is removed as dictated by the individual anatomy in each patient. It is best to remove the maximal amount of the sphenoid wing down to the superior orbital fissure to enlarge the opening at the level of the basal cisterns, especially for ICA or anterior communicating artery aneurysms. In patients with MCA aneurysms, it is not necessary to extend the drilling down to the anterior clinoid process.

**Dural Opening**

The dura is opened in a semilunar manner, providing a 2-mm margin from the craniotomy to facilitate the dural closure, creating a flap that can be retracted anteriorly and secured with sutures or small fishhooks. Even when we do not use spinal drainage in our patients, if a spinal drainage catheter was placed for cerebrospinal fluid (CSF) release at the lumbar thecal sac, this is opened at this moment. Otherwise, furosemide or mannitol can be used at the convenience of the neurosurgeon. In a very few patients, we have found that the former maneuvers were not enough to provide a slack brain; then, a ventricular tap was performed whenever ventricular enlargement was seen on a computed tomographic scan. From this point, the effectiveness of the technique will rely on a wide dissection of the sylvian fissure, avoiding the use of brain retractors to maximize the working space.

**Sylvian Fissure Dissection**

At this point of the operation, the operating microscope is brought into the field, and the surgical view will include the sylvian fissure at the center and the frontal and temporal lobes on both sides (Fig. 1D). The sylvian fissure is identified superficially. Usually, the veins run over the temporal side of the sylvian fissure, and one to three secondary veins cross from the frontal to the temporal side. These veins should be maximally protected. The sylvian fissure is opened superficially over the frontal side, to avoid the veins, with the aid of an arachnoid knife or with the tip of a simple hypodermic needle (the preferred choice of the authors). This maneuver cuts the superficial layer of the arachnoid and provides access to the sylvian fissure itself. First, we go deeply into a small space, and thereafter, we open the fissure wide. As has been reported previously, the sylvian fissure has many anatomic variations, and one should be familiar with them. The dissection is maintained totally in the subarachnoid space to minimize trauma to any cortical surface. In cases of MCA bifurcation aneurysms, opening the distal part of the vallecula will expose the MCA bifurcation and the aneurysm itself. Before dissecting the aneurysm, we should ensure a proximal control from M1, and the sylvian fissure is opened as far as necessary to visualize the main trunk of the MCA. Thereafter, the aneurysm is dissected and clipped. For deeper aneurysms, there is usually a need to dissect the anterior portion of the vallecula, where the sylvian cistern communicates with the basal cisterns. These cisterns should be opened wide for visualization, dissection, and clipping of the ICA or anterior communicating artery aneurysms. With proper brain relaxation, opening of the sylvian fissure requires minimal brain retraction to visualize the parasellar area. In some patients, the brain is tight at the beginning of the dissection, and if necessary, we can make a small opening at the carotid cistern to release CSF and then proceed to complete the sylvian fissure opening. After dissection of the basal cisterns, we can reach the lamina terminalis to open it and facilitate a complete relaxation of the brain. With all these maneuvers, switching from a keyhole approach to a larger craniotomy has never been necessary.
Dural Closure and Bone Flap Placement

After the aneurysm is visualized, dissected, and clipped, a proper hemostasis is verified. The dura mater is closed tight in a water-seal manner with a 4-0 nylon suture. If necessary, a small piece of muscle is used to seal small leakages of CSF. The bone flap is fixed with silk, miniplates, or Craniofix (Aesculap Co., Tuttlingen, Germany), and the temporal fascia and muscle are closed with a 2-0 absorbable suture (Fig. 2).

Skin Closure

The skin is closed with nylon (subdermic or continuous anchored suture) or skin staples, and usually, no drainages are left in place. A small pad is positioned covering the line of suture. We remove the sutures 1 week after surgery unless an absorbable intradermic suture was used for closure (Fig. 3).

DISCUSSION

Recently, the keyhole surgery concept applied to neurosurgical procedures has gained acceptance among neurosurgeons, with the understanding that the keyhole surgery is not the miniaturization of any standard technique but rather the natural evolution into a more precise and refined act. Until now, many approaches have been designed to minimize the surgical exposure. In 1971, Wilson (35) described a limited exposure for aneurysm and tumor surgery with excellent results. Later, Brock and Dietz (8) described a small frontolateral approach for cerebral aneurysms using the subfrontal route. At present, one of the most used keyhole approaches for treating cerebral aneurysms is the subfrontal transciliary approach (synonyms: frontolaterobasal, eyebrow approach) (13–15, 34, 44). This approach provides access to the majority of the anterior circulation aneurysms and basilar top aneurysms, except those located at the distal anterior cerebral artery, in which an interhemispheric craniotomy is commonly used. Some variations to the subfrontal transciliary approach have been reported, designed to gain additional angle of vision (27, 28); however, in our experience, there are two main limitations to this approach. At first, in some cases of MCA bifurcation aneurysms, the M1 segment is too long, and the direction of the dome is lateral and caudal to the surgical view from this approach. In such a case, the amount of dissection required is extensive, and the surgical view and work are in a very deep plane. Furthermore, the occurrence of a thick blood clot around the aneurysm makes the dissection even more difficult. Second, in cases of anterior communicating artery segment aneurysms, the angle of vision with the subfrontal transciliary approach is more rostral than that obtained with the pterional approach, and visualization of the neck area of the aneurysm is not good, primarily if the dome has a caudal direction. In these patients, clipping may be difficult, and the neurosurgeon will never be sure whether a remnant dome is left unless an angiogram is performed during or after the surgical procedure. This problem could be solved in some patients with the aid of a surgical neuroendoscope; however, this device is not available in all hospitals and requires previous training to be used effectively in narrow spaces.

Taking these points into consideration, the standard pterional approach provides a much better access to the MCA region from the M1 segment to the insular branches, so dissection and clipping of any kind of MCA aneurysm is usually in a more superficial plane. Also, visualization of the neck area in cases of ICA-posterior communicating artery aneurysms is from a more lateral angle; then, aneurysms with a dome with a caudal direction are better visualized through this route. The main disadvantages of the standard pterional approach are primarily functional and cosmetic. At first, most neurosurgeons continue to use extensive hair shaving to expose the surgical area, even though there has been no clear demonstration that extensive hair shaving is better in preventing skin infection, and this is sometimes psychologically distressing for some patients. Second, even with the description of many techniques to avoid damage to the frontal branch of the facial nerve and temporal muscle atrophy, these problems continue to occur frequently in neurosurgical practice; and third, if a large incision is made over this area, there will be a marked soft tissue edema, thus increasing the days of hospitalization. Previously, Chehrazi (12) described the temporal transsylvian approach for anterior circulation aneurysms; however, even when this approach is centered over the sylvian fissure and solves some disadvantages of the pterional approach, the line of incision is still located behind the hairline, proceeding from the zygomatic arch toward the anterior extent of the so-called superior “keyhole,” which has disadvantages in patients with a receding hairline. Also, not enough emphasis was placed on an extensive drilling of the sphenoid ridge and the anterior clinoid process, which provides a wide surgical passage for
deeply located aneurysms, relying in this way on the use of mannitol and hyperventilation to attain enough space.

We focused our surgical technique on trying to avoid these problems associated with the classic pterional approach while maintaining the excellent angle of vision that it affords. With the sphenoid ridge approach we describe here, we do not need to shave the hair but only 1 cm behind the natural hairline in the selected area (Fig. 2). Second, the incision over the fascia and temporalis muscle is almost straight, following the natural course of the muscular fibers, thus diminishing the possibility of muscular atrophy. Also, we do not have to make any special kind of dissection to avoid damage to the frontal branch of the facial nerve, because it runs almost parallel to the skin incision. Nevertheless, in our opinion, the most important point to consider in the sphenoid ridge approach is the cisternal dissection and location of the aneurysm. If we analyze any standard craniotomy, our surgical corridor is through the space created by drilling of the sphenoid ridge, which also creates a triangular prism over which lies the vallecula. Thus, it makes no sense to expose extensive areas of the brain behind the sphenoid ridge while we are actually trying to go anterior and medial to it. This approach provides the opportunity to expose the amount of brain necessary to ensure a comfortable opening of the sylvian fissure without special instrumentation and to direct the dissection to the basal cisterns to achieve enough space for gaining vascular control before facing the aneurysm. Again, it should be pointed out that an unavoidable prerequisite before trying to perform this approach is to have enough skills to dissect and open the sylvian fissure and basal arachnoid cistern without the need of using bulky brain retractors.

The main indications for this approach are 1) all anterior circulation aneurysms except distal anterior cerebral artery aneurysms (Table 1), 2) nonruptured aneurysms, and 3) ruptured aneurysm in good neurological grade (Grades I–III of the Hunt and Kosnik classification). On the other side, the main contraindications to the use of this approach are 1) aneurysms associated with a large blood clot with mass effect, 2) paracaninoi or giant aneurysms in which a high-flow bypass is precluded, 3) subarachnoid hemorrhage associated with brain edema and small ventricular size, and 4) patients in poor neurological grade.

The goal of the surgical treatment for cerebral aneurysms is to occlude the lesion without causing harm to the patient. There was a great improvement in surgical results after introduction of the surgical microscope and the description of the microtechniques that are still in use today (38–43). At present, a new alternative for treatment of cerebral aneurysms is available through endovascular therapy. Also, a new generation of neurosurgeons is emerging with new concepts based on minimally invasive neurosurgery (14, 15, 19, 30, 32, 34, 44). In this way, new technological advances, such as neuroendoscopes and navigators, have become a useful aid in surgical procedures; however, many people are afraid that all these advances go against the precise anatomic knowledge that is required to treat a vascular lesion. However, because small approaches require much better anatomic planning, many experienced neurosurgeons have moved away from classic approaches to a keyhole surgery to treat vascular and tumoral lesions (12, 24, 25, 34), so the reports about surgical results and new techniques based on the keyhole concept are increasing worldwide (7, 13–15, 19, 21, 22, 27, 28, 30, 32–34, 44). Perhaps the two main concerns about the keyhole surgery are, first, whether the surgical field we attain through one of these approaches is enough to deal with an intracranial aneurysm, and second, what is the possibility of solving a problem if it occurs during operation (e.g., intraoperative aneurysm rupture, etc.). The response to the first question is related to the surgical planning itself. First, the patient should be carefully selected before surgery according to the recommended indications. In addition, it has been our practice to achieve the softest brain possible before trying to make any dissection over the aneurysm. If we work with a tight brain, the results will be as bad as with any large craniotomy under this condition. If we attain enough space by releasing CSF and using some kind of osmotic agent or any other described maneuver, the anatomic structures will be easily confirmed and the vascular control will be reached without any problems. At the moment of the aneurysm dissection and vascular control, your deep anatomic view should be the same as with any standard craniotomy. The answer to the second question is related to the surgical technique. If you have a comfortable surgical view and vascular control before dealing with the aneurysm, any unexpected complication, such as an intraoperative rupture, should be managed without space limitations. In this sense, the only condition that should be strictly observed is that the craniotomy should be at least 3 × 2.5 cm in size (Fig. 2).

While using the sphenoid ridge approach, we are anticipating that the neurosurgeon will take care of the brain tissue to avoid retraction and damage. The success of this and other keyhole approaches relies on a wide dissection of the cisterns and fissures to open the natural spaces surrounding the brain tissue. It is necessary to acquire laboratory practice to know the use of the aspirator as dissector and retractor at the same time, as well as the use of the bipolar forces in the same sense. At present, on our service, 60% of cerebral aneurysms are treated through a keyhole approach (sphenoid ridge, subfrontal transciliary, micro-interhemispheric). The most important point is that our morbidity and mortality rates did not increase with the use of this approach (5.7% for nonnigant ruptured anterior circulation aneurysms on our service) (Table 2). We now have less operative time (3.9 h with this approach versus 5.7 h for a standard pterional craniotomy), fewer days of hospitalization (7.3 versus 9.2 d), and fewer complications related to the approach itself, and overall, the patients are much more satisfied with the cosmetic results.

REFERENCES

22. Kocaogullar Y, Avci E, Fossett D, Caputy A: The extradural subtemporal approach is well tolerated, is associated with a low rate of attack than the keyhole approach. The orbitozygomatic approach is well tolerated, is associated with a low rate of morbidity, and is easily mastered. The larger opening and

COMMENTS

Minimally invasive surgery constantly struggles to perfect the balance between minimizing tissue trauma and maintaining maximal effectiveness. In aneurysm surgery, exposure is everything. No approach should compromise the principal goals of surgery: safe dissection of the aneurysm, preservation of the perforating vessels, and complete exclusion of the aneurysm from the circulation in a manner that neither endangers the parent vessels nor leaves a remnant.

The optimal angle of attack for dissection and clipping varies for each aneurysm based on the location of its branch on the vascular tree, the orientation of its neck, and the position of adjacent neurovascular structures. The authors’ approach seems adequate to access aneurysms of the middle cerebral artery distribution and most aneurysms arising from branches of the internal carotid artery. It does limit the range of available angles in the axial plane from the frontal trajectory.

For most aneurysms involving the anterior circle of Willis and the upper posterior circulation, we favor variations of the orbitozygomatic approach. Although more invasive, the modified supraorbital approach offers much wider access and a broader range of possible angles of attack than the keyhole approach. The orbitozygomatic approach is well tolerated, is associated with a low rate of morbidity, and is easily mastered. The larger opening and
more extensive dissection are the costs paid to achieve the best possible clipping.

The above being said, the goals of the minimally invasive approach are laudable. In selected cases in which the anatomy is favorable, equally good results may well be achieved through a smaller opening. The authors' technique is one option, and its efficacy is validated by their good results.

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In this well-written report, Nathal and Gomez-Amador describe the sphenoid ridge “minimally invasive” approach for cerebral aneurysms. The described approach has a number of key limitations. The limited bony opening (3 × 3 cm) limits the opening of the sylvian fissure and thus limits access and visualization of aneurysmal parent vessels and associated perforators. The limited access would in turn increase the tendency toward more significant brain retraction. The strategy of clip reconstruction of the aneurysm and circumferential study of and obliteration of the aneurysm is limited. In situations in which untoward events occur, i.e., intraoperative aneurysmal rupture, the surgeon would be limited in effectively controlling the situation with temporary clips in a reasonable manner and thus increasing the morbidity of the procedure.

The pterional transsylvian approach has been time-tested in the effective management of cerebral aneurysms as well as in the scenarios mentioned above. Interestingly, the incision described by the authors (5 cm) is not substantially shorter than that of the pterional approach, which would add only a few additional centimeters, with no significant difference in the cosmetic outcome.

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Drawing of an aneurysm surgery. Inset on the left shows the operative entry with Dandy’s “concealed” incision. Inset on the right shows clip placed on the neck of the aneurysm and the cautery shriveling the sac. Drawing by Dorcas Hager Padget during her work with Dandy, 1929 to 1946 (from Dandy WE: The Brain, Hagerstown, W.F. Prior Co., Inc., 1966).