To improve visual and refractive outcomes, microkeratome-assisted lamellar keratoplasty for the treatment of keratoconus (exchange of a 9.0-mm anterior recipient lamella with a 9.0-mm donor lamella, using a 200-µm head for the former and a 300-µm head for the latter) was modified by adding a 6.5-mm incomplete full-thickness incision in the recipient bed before suturing the donor graft in place. After complete suture removal, 1 year postoperatively, best spectacle-corrected visual acuity was 20/40 or better in 92 of 97 eyes and 20/25 or better in 67 of 97 eyes; regular astigmatism was 4.5 diopters or worse in 86 of 97 eyes; endothelial cell loss averaged 20.4%. The disruption of the recipient’s architecture induced by the full-thickness circular incision makes the final corneal shape closely resemble the physiologic curvature of the donor cornea, thus optimizing postoperative refractive error and spectacle-corrected visual acuity.
formed both in the recipient cornea (using a 200-µm head, as in Figure 1B) and in the donor tissue (using a 300-µm head). The donor lamella was punched to the required 9-mm size (Figure 1C). Then, a 6.5-mm Barron trephine (Katena Products Inc) was centered on the pupil and the blade was advanced until the cornea was perforated (Figure 1D). The inci-

Figure 1. Surgical technique. A, Marking the recipient cornea. B, Microkeratome-assisted dissection of the recipient cornea. C, Punching the donor lamella. D, Trephination in the residual recipient bed. E, Full-thickness incision completed. F, Anterior donor lamella sutured in place.
tion with in-the-bag implantation of an intraocular lens performed through a scleral lens centered on the steeper meridian.

RESULTS

One hundred eyes of 82 patients (44 males, 38 females) were included in the study; their ages ranged from 16 to 64 years (mean, 33.7 years). At the time of this review, all corneas were clear (Figure 2). Figure 3, Figure 4, and Table 1 summarize the results that are reported in detail herein (excluding the 2 cases with buttonholing). Uncorrected visual acuity and BSCVA improved significantly (P <.001) over preoperative values (≥20/200 and <20/40 in all eyes, respectively) at each postoperative examination.

As early as 1 year after surgery, uncorrected visual acuity was better than 20/200 in 57 of 97 eyes (58.8%) while BSCVA was 20/25 or more in 67 of 97 eyes (69.1%). No substantial changes were recorded later. Only 6 patients had a BSCVA worse than 20/40, and this was associated with reasons unrelated to corneal conditions in 3 of them (2 with amblyopia, 2 with retinal disease, 1 with high-degree astigmatism, and central folds [all 3]).

The mean spherical equivalent increased significantly (P <.001) 6 months after MALK. The 1-year values were significantly lower than those recorded at 6 months (P <.001) but significantly higher than the preoperative values (P <.001), and they did not change substantially at a later time. Similar changes (significant flattening, most pronounced with the sutures in place) were also measured for the mean value of average simulated keratometric readings.

Refractive cylinder within 4.5 diopters (D) was measured in only 4 of 100 eyes (4%) preoperatively but in 80 of 97 eyes (82%) and 86 of 97 eyes (90%) 1 year and 2 years postoperatively. Regular astigmatic patterns (symmetric or asymmetric bow-tie) were seen in only 16 of 98 eyes (16%) 6 months after MALK but in 86 of 97 eyes (89%) at 1 year and in a similar percentage of eyes at a later time. Mean (SD) endothelial cell density decreased from 2746 (322) cells/mm² preoperatively to 2186 (331) cells/mm² 1 year postoperatively (endothelial cell loss, 20.4%), with minor changes (P >.05) thereafter.

The complications recorded are summarized in Table 2. In the 2 patients with conversion to mushroom PK, final BSCVA was 20/20 and 20/25 (refractive astigmatism, 3.5 and 2.5 D, respectively) 2 and 3 years after the operation, respectively. The 3 cases with double-chamber formation were managed successfully (Figure 5) with intraocular injection of air through the limbus. All 6 eyes with postoperative epithelial defects persistent for longer than 2 weeks healed with the use of therapeutic contact lenses. Visually significant folds in the recipient cornea resolved spontaneously in 14 of 15 eyes after all sutures were removed (Figure 6).

Late complications included 2 cases of wound dehiscence resolved on the same day of onset (first day after suture removal); 2 cases of corticosteroid-induced cataract, uneventfully managed with phacoemulsification and posterior chamber intraocular lens implantation 2 to 3 years after MALK; and 7 cases of refractive astigmatism more than 4.5 D with BSCVA less than 20/40, all of which underwent relaxing in-
Decisions performed as described in the "Methods" section.

**COMMENT**

Lamellar keratoplasty for keratoconus has not yet been fully accepted among corneal surgeons, as most of them still consider manual and pneumatic ("big bubble") dissection of deep stroma a painstaking procedure with a steep learning curve. Many believe that PK (a technique easily performed by anyone with average surgical skills) offers a better visual outcome with a shorter surgical time.\(^7\)\(^-\)\(^11\) Recently, deep dissection of the recipient cornea, possibly up to the Descemet membrane (ie, deep anterior LK), has been introduced with the purpose of minimizing, if not eliminating, the optically negative effects of a stromal interface and therefore achieving visual results comparable to those of PK.\(^1\)\(^,\)\(^3\)\(^,\)\(^4\) Several attempts have been made to simplify and standardize LK by using either excimer or femtosecond lasers, but concerns remain about the safety and feasibility for the former and the optical quality of the dissection for the latter.\(^1\)\(^2\)\(^-\)\(^15\)

The experience with laser-assisted in situ keratomileusis and, more recently, with Descemet strip-
ping automated endothelial keratoplasty has shown that microkeratome-assisted dissection of corneal stroma is easy to perform and compatible with excellent vision. The microkeratome also has been used for the surgical treatment of keratoconus, with excellent reproducibility. Despite the variability of the preoperative corneal curvature, we routinely obtain a host bed with a regular 9.0-mm diameter, probably as a consequence of the standardized use of a 0 ring for all eyes. However, because of the limited precision in depth of dissection, we aim to leave a layer of residual stroma of approximately 100 µm to avoid perforation. In the previous series, the residual ectatic tissue negatively affected final vision by causing excessive corneal steepening and a high incidence of postoperative irregular astigmatism (9 of 50 patients [18%]).

To maintain the ease and standardization of microkeratome dissection but, at the same time, eliminate the mechanical resistance of the residual bed, we modified MALK by adding a central, 6.5-mm, incomplete full-thickness trephination of the residual bed. As a result, the structure of the recipient cornea collapses after its central part is disconnected from the periphery, while the attachments prevent dislocation of the button. The recipient endothelium and deep stroma are maintained in place and simply adapt onto the posterior surface of the graft after it is sutured in place. The corneal shape as a whole resembles that of the large anterior lamella, and its steepness does not change substantially even after sutures are removed, as the keratoconus memory in the recipient cornea has been cancelled by the perforating incision.

The effect of this modification was such that average postoperative simulated keratometric readings were substantially lower than those of the patients in the previous series, with a mean spherical equivalent closer to emmetropia by about 2 D (Figure 7), similar to that found after PK and less myopic than that observed after deep anterior LK of other types.

Desired absolute values of astigmatism similar to those recorded after PK or LK, the 9-mm graft of MALK produced mostly regular topographic patterns and BSCVA of 20/40 or better in all but 5 eyes. One year after the operation, BSCVA was 20/25 or better in 67 of 97 eyes (69%) and remained substantially unchanged thereafter, improving over previous MALK results (44% of eyes seeing ≥20/25). Overall, visual results after MALK are similar to those of PK or big-bubble LK but better than those of deep anterior LK without Descemet membrane baring.

The “step” wound of MALK adds to the refractive advantages of the 9-mm graft the possibility of performing full-thickness relaxing incisions to correct high-degree astigmatism. This is not possible with any conventional LK, which all use grafts, often 8 mm in diameter, with a straight vertical wound. As in the previous study, we could not identify any effect of the minor peripheral discrepancy resulting between the slanted contour of the surgical wound in the recipient cornea and the vertical edge of the donor tissue.

### Table 2. Complications Recorded During the Study

<table>
<thead>
<tr>
<th>Complication</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buttonholing, conversion into mushroom penetrating keratoplasty</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Double-chamber formation</td>
<td>3 (3)</td>
</tr>
<tr>
<td>Persistent epithelial defects</td>
<td>6 (6)</td>
</tr>
<tr>
<td>Folds in the recipient central cornea</td>
<td>15 (15)</td>
</tr>
<tr>
<td>Wound dehiscence after suture removal</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Corticosteroid-induced posterior subcapsular cataract</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Refractive astigmatism ≥4.5 D</td>
<td>7 (7)</td>
</tr>
</tbody>
</table>

Abbreviation: D, diopters.
In our experience, the very slow motion of the microkeratome has proven instrumental in avoiding buttonholing keratoconic corneas. If the instrument is forced at high speed against the ectatic cornea, it can dislocate the tissue, causing loss of suction and consequent buttonholing. In our series, this complication occurred in 2 eyes with rather low average keratometric readings (54.50 and 58.75 D), thus, independent of cone steepness.

MALK is not an extraocular procedure because of the full-thickness incision; therefore, it exposes the eye to the dangers of intraocular procedures (ie, infection), the same as with other LK techniques, such as the big bubble, which use stab wounds. The endothelial cell loss we measured is somewhat higher than that recorded after other LKs. However, the endothelial cell density remained far above the limits endangering corneal function and stabilized by 1 year postoperatively.

Vision-threatening complications were not seen after MALK. Surgery other than that required to correct astigmatism was necessary only in 2 eyes (uneventful phacoemulsification), thus comparing favorably, especially with the results of PK.

In conclusion, the modification of MALK that we propose maintains all the advantages of other LK techniques over conventional PK. However, in contrast to other types of LK, MALK requires no particular surgical skills, can be fairly standardized, and allows excellent BSCVA in most cases. Complications are rare and can be easily managed by corneal specialists, who may therefore consider adding MALK to their surgical armamentarium.

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