Microneedles are designed to pierce and successfully deliver injections past the stratum corneum, but are too short to stimulate the pain nerves (3, 4). Microneedles exist in two basic designs: in-plane and out-of-plane (Figure 40.1). In-plane microneedles have been integrated with circuitry, pumps, and sensors (5–7) and have been used in clinical tests to measure blood glucose levels (8). Reed and Lye (9) provide an extensive review of in-plane microneedle fabrication methods. In-plane microneedles are more easily integrated with electronic processes, but a disadvantage is that fabrication is restricted to one-dimensional arrays (9). Out-of-plane microneedles can be incorporated into two-dimensional arrays that allow for drug delivery over a greater area, similar in design to a "patch."

Out-of-plane microneedles have been fabricated in several designs. Solid microneedles have been shown to increase skin permeability (3). Hollow microneedles were subsequently developed so that fluid could be injected through them (10–13). Although most microneedles have been fabricated out of silicon, others have been fabricated from glass (11), metal (11), and polymers (11, 14). Stoeber and Liepmann (10) fabricated a microsyringe backing along with the microneedle array and measured *in vitro* dye injection depths of 75 to 100 µm. Some *in vivo* injection studies have been performed with out-of-plane microneedles, but few human studies have been done. Kaushik et al. (4) carried out the first human study to show that microneedles were painless upon insertion. Sivamani et al. (15) performed clinical injection studies and showed that microneedles helped compounds bypass the stratum corneum more quickly. Prausnitz (16) provides an overview of solid microneedle *in vivo* studies that investigate insulin permeability and vaccine delivery. McAllister et al. (11) used a single glass microneedle to inject insulin into diabetic rats and reduce their blood glucose by 70%. Gardeniers et al. (12) infused insulin into diabetic rats through a microneedle array and showed that it was comparable to subcutaneous insulin injection. Matsuda and Mizutani (14) implanted polymer microneedles for a month in rats to study the polymer degradation characteristics.

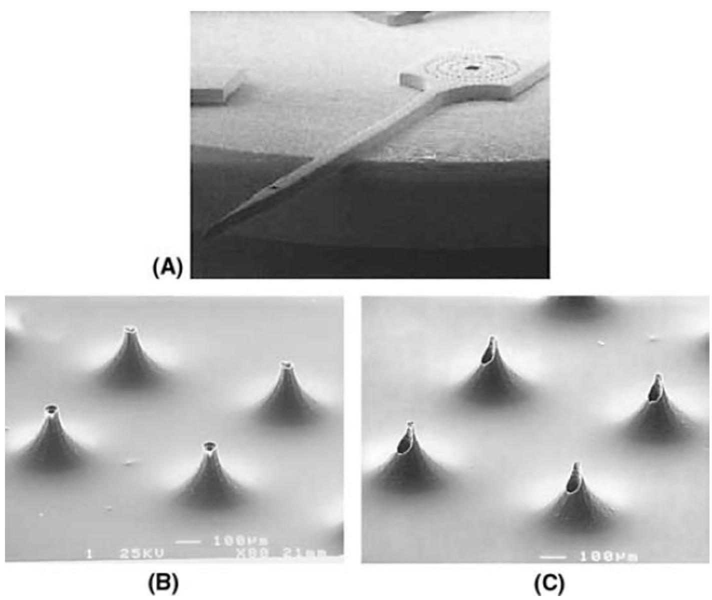

FIGURE 40.1 Silicon microneedles. (A) In-plane microneedle (5), (B) symmetric hollow microneedles, and (C) pointed hollow microneedles. The symmetric and pointed hollow microneedles are approximately 200 µm high with a lumen diameter of 40 µm.