Impact of Microscopic Foreign Debris on Post-Surgical Complications

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ABSTRACT

Minute pieces of debris left in the surgical site can interfere with optimal wound healing. Even when these microbodies are not obvious without magnification, their presence can cause post-surgical complications including infections, amplified and prolonged inflammation, permanent tissue damage, exaggerated and reduced quality scarring, granulomas, adhesions, organ dysfunction, infertility, and other pathological consequences. This chapter reviews foreign debris-initiated, post-surgical complications; presents associated pathological mechanisms; identifies sources of debris contamination; describes foreign-microbody characteristics that can further amplify pathological responses; and presents recommendations for minimizing their presence.
One of the most important attributes of living organisms is the capacity to self-repair. This ability is expected and observed every time a major or minor invasive procedure is performed on a patient. Needless to say, lack of this healing ability would render surgery useless. Every injury, whether a broken leg, bloody nose, or paper cut, would be a potential death sentence. If the body’s healing systems were present but only minimally effective, one might make it through childhood spills, preadolescent tumbles, and sports warrior clashes alive, but seriously scarred, misshapen, and minimally functional.

Instead, a surgeon removes an appendix, sets crushed legs, and performs brain surgery assuming (or at least, expecting) normal wound-healing repair will occur in an automatic sequence within a fairly predictable time period. Simplistically, all that is necessary is to make sure the parts are kept moist and clean, properly aligned, and adequately bound. Although the auto-pilot repair process initiates to some degree in any individual, the quality of repair can vary substantially depending on the condition of the patient’s general health and well being, degree of trauma, oxygen tension in the affected tissues, presence of foreign microbodies, level of microbial contamination, local temperature, etc.

Suboptimal conditions can delay or interrupt the auto-processing sequence of repair which produces anomalies ranging from dehiscence to excessive scarring; positioning slip to severe adhesions; discreet granulomas to purulent discharge; and internal intact abscesses to ulcerous, open lesions. As our understanding of the “ideal environment” expands, so does the list of procedural directives. One area that has had considerable focus in some specialty procedures, but is often neglected in others, is the impact of foreign microbody contamination on post-surgical complications.

**Table I**

<table>
<thead>
<tr>
<th>Foreign Microbodies</th>
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<tr>
<td>Lint/fibers</td>
<td>Glove cornstarch powder</td>
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<tr>
<td>Sutures</td>
<td>Bone fragments</td>
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<tr>
<td>Degraded/worn implants</td>
<td>Burned tissue</td>
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<td>Hair</td>
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**FOREIGN-BODY-ASSOCIATED INFECTIONS**

Foreign-body-associated infections have been reported extensively in the literature. Infections following the implantation of catheters, open drains, vascular grafts, heart valves, and prosthetic materials are very familiar. When a staphylococcal abscess is discovered on a synthetic vascular graft months after surgery, little doubt exists that the etiology was a foreign-body-associated infection.

However, the cause-and-effect relationship is less obvious when the foreign materials are too small to be readily visible. At the foci of a nodular abscess, there may be a piece of suture; lint (fibers) from drapes, gowns, caps, lap sponges; or powder particles from surgical gloves. Seldom do surgical-site infections involve histopathological investigations beyond identification of the infective microorganism and its antimicrobial susceptibility. Foreign microbodies distract and occupy the attention of the local immune defenses, which allow otherwise harmless levels of microbial contamination to multiply unimpeded. The few incidental tran-
Absorbable

Non-Absorbable

(Fig. 1).

allowed to rapidly become an infection phagocytized and destroyed, are sients, which would normally have been phagocytized and destroyed, are allowed to rapidly become an infection (Fig. 1).

These observations have been noted experimentally by Elek and Conen' and Noble who demonstrated in classic suture abscess models that an initial inoculum of 100 (10²) colony forming units (CFU) of Staphylococcus aureus would cause an infection. Without the suture fragment, an inoculum of 10,000,000 (10⁷) CFU injected subcutaneously was incapable of producing an infection. In addition, Edlich et al. determined that some sutures are more potent adjuvants of bacterial proliferation than others. The effect of the suture fragment on the local tissue defenses depends on the configuration (braided or monofilament), chemical composition (Table III), diameter, and length of the fragment.

Jaffray et al. demonstrated a similar decrease in the level of inoculum needed to initiate an infection using cornstarch powder instead of suture fragments. In this study, 1 of 10 wounds became infected when 1000 (10³) CFU of Staphylococcus aureus was present without foreign debris. When 2 mg of sterile glove cornstarch powder were also placed in the wounds, a sustained infection was observed in 9 of the 10 wounds. When considering that a pair of sterile powdered surgical gloves can easily have 300 mg of powder, 2 mg is quite low. In a more recent study, Ruhl et al. also confirmed that glove powder significantly reduces the local resistance to infection.

Zimmerli et al., and more recently Renz and Gemsa, experimentally elucidated the mechanisms by which the efficacy of the local immune system is diminished in the presence of foreign debris. Using Teflon fibers, Zimmerli et al. demonstrated that when polymorphonuclear leukocytes (PMNs) come in contact with foreign debris that is too large to be phagocytized, they expel myeloperoxidase in the direction of the microbodies attempting to kill the perceived threat. This threat leaves local PMNs with diminished phagocytic capability, reduced granule content, and diminished capacity to mount a respiratory burst. As PMNs are the first line of defense, the burden of protection in the tissues is then shifted to the macrophage.

Renz and Gemsa performed in vitro macrophage experiments using powder rinsed from sterile surgical gloves. Between 100 and 300 million particles were collected from each glove. Challenge suspensions were diluted to deliver two powder particles per macrophage. The powder microbodies initiated the release of large amounts of tumor necrosis factor (TNF), interleukin 1, prostaglandin E₂, thromboxane B₂, and hydrogen peroxide. Interleukin 1 is an important mediator of the inflammatory response that acts as a co-stimulatory factor for T-cell activation and mediator release. TNF is also a potent stimulator of the inflammatory response that causes vasodilation and redirects additional inflammatory cells to the local area. The prostaglandin products also play a major role in the inflammatory activity by inducing pain, vasodilation, cell redirection, up-regulations of adhesion molecules, and activation of endothelial cells.

Release of these inflammatory mediators is associated with increased macrophage death, confirmed by quantitative measurement of lactate dehydrogenase (LDH)–an enzyme released by a macrophage when it dies (apoptosis). The dying macrophage releases the fully or partially ingested foreign microbodies. Additional macrophage cells that have been redirected to the area then attach to these released particles, resulting in further heightened inflammation and repeatedly thwarted defenses.

Whether the foreign microbodies are powder particles, suture fragments, or lint fibers, the micro-environmental conditions altered by release of these toxic moieties and hydrolytic enzymes initiate local hypoxia, acidosis, and fibrin deposition. The oxygen tension in a foreign-debris-contaminated wound can be measured in the 20 mmHg range compared to healed wound tissue values of approximately 40 mmHg. This reduced available oxygen further inhibits microbicidal capability. The

### Table II

<table>
<thead>
<tr>
<th>Complications Reported</th>
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<tbody>
<tr>
<td>Intestinal obstruction</td>
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<tr>
<td>Infertility</td>
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<tr>
<td>Toxic lens syndrome</td>
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<td>Loss of visual acuity</td>
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<tr>
<td>Stroke</td>
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<td>Phlebitis</td>
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<td>Kidney loss</td>
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<td>Implant rejection</td>
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<td>Seizures</td>
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<tr>
<td>Misdiagnosis as disseminated carcinoma</td>
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<tr>
<td>Death</td>
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### Pathology

- Amplified and prolonged inflammation
- Delayed healing
- Reduced local resistance to infection
- Granuloma formation
- Thrombus formation
- Adhesion formation
- Ischemic tissue death
- Pain
- Excessive scarring
- Poor scar strength
- Sterile purulent discharge or abscess

### Table III

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<th>Potentiating Capacity</th>
<th>Absorbable</th>
<th>Non-Absorbable</th>
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<tbody>
<tr>
<td>Least to Highest</td>
<td>Synthetic</td>
<td>Nylon (polypropylene)</td>
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<tr>
<td></td>
<td>Plain gut</td>
<td>Dacron</td>
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<tr>
<td></td>
<td>Chromic gut</td>
<td>Metal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silk</td>
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increased fibrin deposition sequesters and protects multiplying microorganisms, which allows them to strengthen their foothold in the tissue until, finally, a local infection is established (see Fig. 1). Thus, the presence of foreign microbodies in the surgical site increases the risk of post-surgical infection both by thwarting the efficacy of leukocyte defenses and altering the local tissue environment, making it more favorable for microbial growth.

A purulent discharge, or pus-filled abscess, may or may not be positive for microbial growth. The absence of microbial confirmation is not uncommon. The perpetuating cycle of leukocyte recruitment and death produces pus as the dead white cells fall into the increasing serous fluids of the escalating inflammatory response even without microbial contamination. In some situations, the purulent discharge may be sufficient to require drainage in order to prevent pressure damage to more delicate structures. A foreign microbody or debris reaction should be considered when sterile pus continues to be present.

It is important to emphasize here that microbodies—including powder and lint—may carry microorganisms. Whether the microorganisms come from the environment (inside or outside of the Operating Room (OR)), staff members, or the patient, they can attach to microbodies and be dispersed into the air and/or deposited onto instruments and directly or indirectly into surgical wounds. In the wound, these microbial-laden microbodies deliver both the inoculum and "defense interference" to the surgically traumatized host, which establish all the components necessary for an opportunistic infection.

Cost

Nosocomial infections are expensive. Surgical-site infections develop in 2%-5% of the 50 million U.S. surgical patients per year, which increases their hospital stay by an average of 7.4 days. The increased U.S. annual hospital costs attributed to surgical-site infections is estimated to be $130-$845 million per year. Wong estimates total costs including indirect expenses related to surgical-site infections may exceed $10 billion annually.19

- **Abscesses (lint):** Two patients developed cellulose fiber-initiated intra-abdominal abscesses. Lint captured while handling cellulose-based disposable gowns and drapes used in the OR were identical to those in the granulomas.20

- **Sterile pus and seizures (powder):** After meningioma removal, a 42-year-old female experienced focal fits and a grand mal seizure. After 10 days, evidence of intracranial shift of midline structures necessitated re-surgery. No hematoma or other obvious cause for her difficult recovery was noted. She improved until 14 days after the second craniotomy when the wound became painful and copious quantities of sterile pus were discharged. Histopathological examination of the wound tissues revealed glove-
powder granulomas. A third craniotomy was performed, and unhealthy granulation tissue was removed—this time without powder contamination of the site. Recovery was excellent. The total hospital stay from the date of the first procedure was two months.21

As discussed, the frustrated defensive activities of PMNs and macrophages serve to amplify the local inflammatory response above that needed to initiate normal tissue repair secondary to any invasive procedure. Once the PMNs exhaust their attack efforts and the macrophages infiltrate the site (9-48 hours), their activities continue to heighten as more and more of these cells expend their efforts and die. Each phase of leukocyte activity not only adds to the tissue damage, but also continues to create "dead cell debris," which further escalates the inflammation and increases leukocyte infiltration. Collateral damage inflicted on healthy tissues by the frustrated white cells perpetuates the inflammatory response through a variety of mechanisms including the activation of kinin, coagulation and complement cascades, as well as deposition of fibrin.10

Symptomology depends on the level and characteristics of foreign-debris contamination, location of the surgical site, and the patient's physiological makeup and treatment regimen. If the level of debris contamination is significant and the surgical site is in the abdominal region, the large volume of fluid access allows for significant amplification of inflammatory swelling. Several liters of extravascular serous fluids have been drawn from foreign-body-induced peritonitis.22 Furthermore, the level of swelling can be sufficient to cause dehiscence of the healing wound (Fig. 2). If the foreign debris is such that it eventually dissolves, or is broken down and removed by the immune system, the amplified inflammatory response may resolve after a prolonged recovery.

**Figure 3A.** Shows a 2-cell embryo where the growth media came in contact with gloves compatible with the embryo.

**Figure 3B.** Illustrates contact with sterile gloves containing embryotoxic chemicals.

**Figure 3C.** Shows the same contact of the growth media on fibroblasts with a biocompatible glove.

**Figure 3D.** Illustrates contact with a glove that contains cytotoxic chemicals.

**Figure 3.** The physical presence of foreign debris in a surgical wound heightens the inflammatory response by its presence. The biological response may be increased when cytotoxic chemicals, chemical sensitizers or endotoxin is carried on the particle.
The patient may have been subjected to additional swelling, pain, fever, malaise, nausea, wound-care activity, or experienced some exaggerated scarring, but recovered. Alternatively, if the foreign debris continues to resist effective dissolution and continues to aggravate immune responses, the inflammatory process will progress to chronic status. Lymphocytes, plasma cells, mast cells, and eosinophils are usually involved in this more persistent inflammatory state. The various cytokines and mediators they release keep the process recycling if the debris remains. If the reparations at the incision site continue to hold, fibrin is deposited while local tissues continue to swell, which necessitates the spanning of larger spaces with a more extensive fibrin volume. Normal fibrinolytic activity has been shown to be hindered by the presence of some types of debris. When the self-destruct fibrinolytic activity is only partially active, the residual fibrin is overlaid with collagen and the scar becomes hypertrophic. It is interesting to note that such scars often have less tensile strength and elasticity on hypertrophic scars formed subsequent to glove-starch contamination, as noted in studies performed by Corless et al. (see Fig. 2).23

**Excessive scarring (fibers):** A 54-year-old diabetic underwent radical mastectomy. Considerable pain, serous drainage, and general inflammation were noted. Wound edges remained erythematous and healing was slow. Four months later, the hard, irregular, unattractive scar was excised. Resurgery and 10 extra days of hospitalization were required. Early aesthetic healing ensued. Histology of specimen revealed cellulose fiber granuloma (one fiber, not a plethora of debris).24

**Opthalmic complications (fibers/powder):** The Journal of Refractive Surgery reported 100+ cases of diffuse lamellar keratitis following LASIK surgery until environmental particulate contamination was identified and resolved.25 Foreign microbodies have also been a contributing factor in the etiology of sterile endophthalmitis,26,27 toxic lens syndrome,28 ocular fibrosis,27 recurrent uveitis,26 and severe ocular inflammation29 (particulate dose dependent), resulting in diminished visual acuity.

**IVF failure (powder):** In vitro fertilization labs have experienced embryotoxic episodes associated with powder from powdered gloves.29 The actual toxicity may be associated more appropriately with the glove chemicals absorbed by the powder, as studies have shown that glove chemicals can be cytotoxic depending on the type and amount of chemical used in production.30

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Figure 4. Giant cells with peripheral nuclei are indicative of an immunological reaction (as in Type IV, delayed hypersensitivity to the foreign microbody). Nuclei dispersed throughout the giant cells in this forming granuloma are indicative of a foreign body reaction.

Figure 5A. Foreign microbody-associated granuloma with consequent inflammatory response. Photograph provided by Mediscan

Figure 5B. Suture fragment granuloma. Photograph provided by Mediscan
Adhesions are responsible for over 40% of intestinal obstructions and 60%-70% of small bowel obstruction. The likelihood of adhesion-induced infertility increases with the number of abdominal or thoracic procedures. Figure 6. Adhesions around fallopian tubes or between fimbræ are a significant cause of infertility. The photograph provided by Mediscan.

Delayed Hypersensitivity), and the patient has been previously sensitized, the granulomatous activity and inflammatory response will be significantly more profound. What would have been a papule formation in an allergic contact dermatitis is expressed as a granuloma in the interior of the wound. In the early stages of the immunologic response, the attacking macrophage ingests a piece of the foreign debris and presents to appropriate T-lymphocytes, which causes them to activate. In so doing, the T-cell produces and releases cytokines that activate other T-cells and more macrophages, exacerbating and perpetuating the response.

It is possible that persons genetically capable of developing a Type IV hypersensitivity to a particular chemical on (or within) the pieces of foreign debris, have not yet been sufficiently exposed to have reached their individual threshold for symptom expression to that particular antigen. However, the slow leaching of an antigen from a particle being gradually dissolved may be sufficient to initiate a delayed hypersensitivity reaction later in the post-surgical recovery period. The delay in reaction makes the temporal connection to the surgical procedure more of a challenge.

Other foreign-microbody-initiated "clumps" are generated by alternative mechanisms. Foreign microbodies may be deposited within the circulatory system during procedures such as vascular or cardiac repair, cardiac catheterization, or when establishing a central venous line where they can attract platelets and initiate coagulation. Additionally, particles may injure vessel walls triggering the coagulation cascade. The microbodies become wrapped in platelets and leukocytes forming clots, potentially the cause of post-surgical complications that involve both morbidity and mortality.

If the particle surface texture is sufficiently abrasive, the composition is toxic, or the particle is contaminated with endotoxin, complement is also activated. Injury to the vascular lining may then spread beyond the immediate point of particle entry, which increases the area impacted by inflammation. Particular contamination of the circulatory system has been associated with morbidity including strokes, cardiac infarction, local and remote tissue ischemic damage, deep vein thrombosis and phlebitis, as well as mortality.

- Infant bilateral scrotal masses (powder): Surgery was performed on a 2-month-old male infant with bilateral scrotal masses resulting from foreign-body reactions to glove powder. A pyloromyotomy was performed in the neonatal period. Later, the powder particles migrated from the surgical site to the scrotum.

- Fatal embolism (suture): Following mitral valve replacement surgery, a suture fragment escaped detection and fell into the circulatory system. A thrombus formed rapidly around the suture, which subsequently lodged in the left anterior descending coronary artery.

- Mitral valve death (powder): Subsequent to catheterization and mitral-valve-replacement procedures, a patient died of acute mitral occlusion from a flapping mural thrombus. Histopathological analysis identified foreign microbodies at the center of the clot.

- Stent implantation (fibers/powder): Whelan et al. observed substantial contamination of coronary stents with textile fibers, glove powder, or both, during experimental preparation and implantation. Of those studied with stent thrombosis, 41.6% of the implants...
possessed starch contamination with no fibers detected. Of those who did not experience stent thrombosis, 11.8% were contaminated with powder and 8.8% with textile fibers. It was noted that some of the powder granules were large enough to easily clog the capillaries in which they were lodged. They also noted both powder particles and fibers covered with adherent inflammatory cells and platelets, with fibers incorporated into a newly formed neointimal layer.35

Granulomas (fiber): Tinker et al. reported 45 consecutive cases of cellulose fiber granuloma with mild-to-severe consequences. Of the 45 cases, 27 were extraperitoneal and 18 were intraperitoneal.36

Donor kidney contaminated (powder): Microbodies from perfusate contaminated with glove powder have been shown to render kidneys unacceptable for transplantation, as particles had become lodged in the renal vessels and glomeruli.37

Whether the debris initiates exaggerated inflammatory activity due to foreign microbody activation or secondary to a delayed hypersensitivity reaction, fibrin is deposited. The strands form a scaffolding or matrix that facilitates the movement of fibroblasts and leukocytes through the edematous and dynamic area.15 Granulomas may be overlaid with fibrin where they function as a web to wall off the unwanted mass and often serve to

Figure 7A. Wood Pulp (paper).

Figure 7B. Wood Pulp/Polyester with Adhesive Binders.

Figure 7C. 280- count Polyester/Cotton washed.

Figure 7D. Polypropylene SMS (Spunbond/Meltblown/Spunbond).

Figure 7. These photomicrographs of surgical fabrics illustrate most commonly used materials. It is apparent that fabrics A, B, and C will readily produce lint when the material rubs against itself, the surgical table, or other objects. D is a much smoother material with weld points to anchor the extremely long polypropylene filaments making it more difficult to create lint.

ADHESIONS
attach the granuloma (or clot) to a nearby structure. Prior to “anchorage,” granulomas may move with gravity and fluid currents to remote sites of the body or remain suspended if a high level of fluid is present, as in the case of peritonitis.

Once anchored to a structure, more fibrin is deposited, which adds girth to the nodule. Both ends of each fibrin strand deposited must attach to something, perhaps to surface points on the granuloma, the base structure to which the granuloma is anchored, or adjacent tissues or organs. As an inflammatory response begins to resolve, the scaffolding of fibrin is no longer required. In normal healing, fibrin “self-destructs” with the release of fibrinolytic enzymes.

Researchers have reported that upon histopathological examination some foreign particles (eg, glove powder) may eventually dissolve, leaving little or no trace; however, the granulomas and adhesions they initiated may persist potentially causing intestinal obstruction and infertility. Thus, the percentage of adhesion formation initiated by foreign microbodies may be much higher than actually reported.

Table IV represents the findings of histopathological studies on the etiological agents of post-surgical complications that focus primarily on adhesions. The large differences in frequency percentages among the studies presumably depend on the products used in the OR, environmental controls, and personnel practices.

In the United Kingdom, with a population of about 50 million people, approximately 18,000 procedures for amelioration of adhesions are performed annually. Mortality rates range from 3%-5% for simple obstructions to approximately 30% when the intestine is strangulated, necrotic, or perforated.

Cost

In Europe, a total of 59 patients admitted to the University Hospital, Rotterdam, for symptoms related to adhesions were followed closely for costs associated with their medical management. Of these, 35 required surgery for adhesiolysis. The complication rate was high (70%) with a 13% operative mortality rate. Financial costs were recorded as DFI 1,209,433 (approximately $720,000 U.S.). Costs included:

- Surgical and operative clinic: 7.7%
- Intensive care: 6.5%
- Laboratory & diagnostic tests: 7.6%
- Out-patient care: 4.8%
- Medications: 3.4%

Table IV

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<tbody>
<tr>
<td>Lint (or fibers)</td>
<td>80%</td>
<td>NN</td>
<td>26%</td>
<td>16%</td>
</tr>
<tr>
<td>Cornstarch Powder</td>
<td>3%</td>
<td>5%</td>
<td>2%</td>
<td>1%</td>
</tr>
<tr>
<td>Sutures</td>
<td>2%</td>
<td>25%</td>
<td>NN</td>
<td>&lt;1%</td>
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<tr>
<td>NN = Not noted in report</td>
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Adhesions are currently the main cause of bowel obstruction in Western countries and account for more than 40% of cases of intestinal obstruction and 60%-70% of those involving the small bowel. Adhesiolysis for bowel strangulation or obstruction has a mortality rate of 10%. A 1988 U.S. study calculated 281,982 hospitalizations for lower-abdominal adhesiolysis required 948,727 days of inpatient care, at a cost of approximately $1.2 billion of direct hospital costs. U.S. cost calculations were exclusive of out-patient and indirect patient-care costs.

**Intestinal obstruction (fiber):** A 26-year-old female 2.5 weeks after bilateral ovarian cysts were removed was re-admitted with intestinal obstruction. Surgery revealed bowel severely adherent to all surrounding structures, which was beefy red, indurate, and friable. Recovery was slow, painful, and the patient was febrile. A 4-week course of prednisone provided marked improvement. An additional 4 weeks of hospitalization were required. Histopathology of adhesions revealed foreign-body reaction to cellulose fibers.

**Kidney strangulation (powder):** A 21-year-old female suffered severe retroperitoneal fibrosis with chronic inflammation, pain, and nausea four months after ureterolithotomy. Abdominal exploration showed the entire right ureter encased in hard, dense, adhesions, which strangled the blood supply to the area and necessitated a nephrectomy. Histopathology identified heavy foreign-microbody contamination imbedded in granulomas throughout the adhesion tissues.

**Peritonitis and adhesions (fiber):** Janoff et al. identified 24 cases of cellulose fiber granulomatous reactions in three Portland area hospitals. Six of these patients suffered severe granulomatous peritonitis with significant morbidity and one mortality. Six other patients had adhesions and granuloma formation that required re-operation, but they did not have diffuse peritonitis. Six more experienced acute abdominal pain and intestinal obstruction with dense, thick, adhesions.

- **Intestinal obstruction (fiber):** Although contamination of surgical sites with foreign debris will never be entirely prevented, the products used and practices implemented in the OR can significantly affect the level and reactive potential of foreign microbodies inadvertently implanted. Adverse reactions are amplified and the mechanisms expanded by the physical characteristics of the microbody, base material of composition, and type and amount of substances absorbed to its surface.

In general, if the size is equal, smoother particles typically elicit less reactivity than angular or jagged surfaces. Both the physical configuration and base chemical composition of sutures, for example, impact the biological response. Braided, thicker sutures are generally more bioactive than thinner, monofilament sutures. The braided structure also presents more protected areas, which may sequester microbial growth. Composition of the base material is significant not only as a potentiator of surgical-site infections, but also with regard to its capacity to amplify inflammation (see Table III).

In vivo experiments and post-surgical case studies noted varying levels of pathological response to foreign debris that may be related to the patient, but appear at other times apparently dependent on variations in the composition of the lint, glove powder, suture, etc.

Treatments and the presence of absorbed substances also impact the type and level of pathological response. Studies have demonstrated that cornstarch powder itself is capable of producing foreign-body and inflammatory reactions. After placement onto the surface of the glove, powder particles may also absorb unbound glove chemicals, which can cause dermatitis on the hands of healthcare professionals and others who wear gloves. As granulomas and adhesions may be formed as a result of each of these biological reactions, it is possible that more than one mechanism is involved for any patient with these complications. More severe reactions may often be experienced by individuals who have a Type IV hypersensitivity to the powder or, even more likely, to one or more of the glove chemicals being slowly leached from its surface.

The fabrics from which items used in the OR are made vary tremendously in their capacity to generate lint. The photomicrographs displayed (Fig. 7) show the more easily abraded surfaces of the wood pulp, wood pulp/polyester,
and washed cotton fabrics compared to the smooth polypropylene Spunbond/Melt-blown/Spunbond (SMS). The wood pulp and wood pulp/polyester fibers snag easily and are readily released from fabric as lint. The polypropylene SMS microstructure is made of continuous filaments "welded" together at frequent points to prevent accessibility to the strands. However, it is important to note that some manufacturers of SMS drapes use materials such as wood pulp/polyester in the fenestration inserts to increase absorption properties. This practice, however, increases linting at the most critical area—the surgical site.

Edmiston et al. reported a dramatic drop in particulate contamination when polypropylene replaced the existing wood pulp/polyester fabrics. They also reported that it took several weeks for the lint from wood pulp/polyester fabrics to be cleaned entirely from the room, as lint from fabrics removed days and weeks previously continued to be recovered from air-sampling filters proximate to the surgical site (Fig. 8) and tweezed from potentially critical surfaces (Fig. 9). Interestingly, several hospitals became aware of lint contamination when maintenance changed intake filters of particulate-sensitive computers. Lint had clogged the filters and caused the control systems to overheat. The color of the trapped lint made the source of the contaminating debris obvious.

Verkkala et al. demonstrated that by changing the OR staff garments and textiles from which they were constructed, the airborne particle counts fell from 850 particles/m³ to 50 particles/m³, microbial counts dropped from 25 CFU/m³ to 7 CFU/m³, and wound contamination dropped 46% during sternal surgery and by more than 90% during leg surgery.

Surges in airborne-particulate production may occur when fabrics rub together, move against the OR table, or when instruments are moved across their surfaces (abrasion). Paper seals that fray upon opening and lasers tested on items that disperse particles may cause surges as well. Surges may also be created by increased movement in the room or when doors are opened or closed. Furthermore, when powdered gloves are donned and snapped, removed and tossed, or punctured, a surge of particulates is created.

In addition, microbodies may be attached to medical devices. For example, Green reported that the surface of nylon catheters acquired a static charge when removed from plastic packaging, which increased the attraction for, and clinging of, particles to the surface of catheters. The particulate contamination initiated heavy fibrin deposits over a 26-hour period with the heaviest deposition over delivery ports, potentially reducing drug flow.

Stein similarly reported that instruments used in ocular surgery attracted powder by way of static charge imparted to the surface of the instruments after they had been pulled across sterile plastic drapes.

Endotoxin is another inflammatory, potentiating contaminant present in association with some microbodies (glove powder, fibers). Depending on the amount of endotoxin (pyrogenic lipopolysaccharides from the cell walls of Gram-negative bacteria), the adverse events may range from heightened inflammation (low), compliment activation, fever, clot formation, reduced perfusion (of the heart, lung, and kidney), and disseminated intravascular coagulation (DIC) to endotoxic shock (high). It is interesting that while there are strict requirements for non-pyrogenicity (low endotoxin) for most intravascular devices, including heart valves, vascular grafts, and angio-caths, there are no endotoxin limits on the gloves that handle them directly.

◆ Fever (powder/endotoxin): Febrile responses occurred in 8 of 69 patients after cardiac catheterization. Pyrogens were detected on catheters only after being handled with sterile powdered gloves. Incidence of febrile reactions was reduced from 11.6% to 0.6% by first rinsing gloves with pyrogen-free water prior to handling catheters.

Appropriate tissue preparation prior to in vivo studies of foreign debris contamination is essential. Studies have demonstrated that tissue must be traumatized to appropriately simulate the surgical environment. Without this preparation, studies may yield false-negative results that may be interpreted to be biocompatible.

When comparing study conclusions or merits, the relevance to the condition of the patient, local wound environment, particle characteristics, and implantation technique is critical to correctly assess the microbody’s potential for causing post-surgical complications.
RECOMMENDATIONS

Select low-linting or lint-free products whenever possible. If linting fabrics are used, care should be taken to avert the generation of airborne particulates. Unfold or roll out rather than shake out drapes. Avoid tearing paper products in the OR. Do not rip tape from the sterilization wrap to which it is attached; tear the tape itself instead. Cotton fabrics produce more lint after repeated washings than they do when first used (Fig. 7C). Thus, appropriate evaluation of this material should be conducted throughout the life of the fabric.

The source of linting in the OR may be revealed by having maintenance save all, or part of, the filters and pre-filters used in the OR air circulators for observation. Replacement of filters for particulate-sensitive instruments and data systems is very expensive. The move to low-linting, powder-free products demonstrates a cost avoidance that may be helpful for upfront cost justification, both in postoperative patient care and routine instrument maintenance.

Surgical gloves should be powder-free. OR efforts to remove powder from powdered gloves have not been successful. Acknowledging the potential adverse consequences of glove cornstarch powder, the U.S. Food and Drug Administration (FDA) has required a cautionary statement to be placed on all powdered surgical gloves that reads:

Caution: “After donning, remove powder by wiping with a sterile wet sponge, sterile wet towel or other effective method.”

U.S. compliance to this mandate has been estimated to be 10%-17%. However, studies have shown this method to be inadequate for powder removal. Although iodine removes powder more effectively, the method is messy and expensive. More importantly, any iodine-contaminated powder clumps left on the glove are more bioactive than starch alone. Others have tried powder removal with alcohol, but this method still leaves clumps and powder in crevices that come forth when the hands are flexed. Alcohol also degrades several glove materials, which reduces barrier integrity and increases the risk of OR fires.

Even the best method of removing powder from powdered gloves is worthless in protecting the patient if the gloves are punctured during the procedure, as powder from the inside of the glove may spill into the surgical wound. The only way to ensure powder microbodies do not contaminate the surgical site is for surgeons, OR staff, and instrument-handling personnel to use powder-free gloves.

Select monofilament, thinner-gauge sutures made of less provocative materials when possible, and remove all trim fragments from the surgical site.

It is strongly recommended that granuloma and adhesion specimens be analyzed microscopically or with chemical-analysis techniques to identify etiological agents. The histopathologist can observe prepared tissue sections microscopically for the presence of imbedded debris. By altering the light source for polarized light microscopy (Fig. 10), glove powder and cellulose fibers may be identified (birefringence or Maltese Cross formation). Alternatively, Lugol’s (stains starch particles purple) or periodic acid Schiff (PAS) stain (stains starch particles deep pink) may be used for starch identification.

CONCLUSION

To recognize the impact foreign-debris contamination has on post-surgical outcomes, it is critical that histopathological investigations be conducted when complications occur. The etiological agent of the granulomatous disease or adhesion should be identified. Although foreign microbody complications may be treated successfully, the optimum goal is prevention. To avoid direct and indirect contamination of the surgical site with foreign microbodies, select low-linting OR and Central Service fabrics and maintain practices that reduce particulate generation. Gloves should be powder-free not only for the surgeon, but for all OR staff members and those preparing and handling surgical devices. Use the most biocompatible sutures appropriate for the procedure and remove all trim fragments. Reduction in patient morbidity and mortality, as well as cost and time expended, make foreign-microbody contamination control well worth the effort.

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