# Effect of activated charcoal dressings on healing outcomes of chronic wounds


• **Objective:** To compare the ability of activated charcoal dressings with that of a hydrocolloid dressing to reduce the wound area of chronic wounds.
• **Method:** Two separate randomised controlled trials (RCTs) were undertaken; both used the same hydrocolloid as the control. One RCT compared Actisorb (without silver) with the control on chronic pressure ulcers and the other RCT compared Actisorb Silver 220 with the control on chronic venous leg ulcers. Patients were followed for four weeks. Baseline patient demographic and wound characteristics were comparable between the treatment and control groups. Wounds were assessed at weekly intervals. Ulcers were photographed and then traced by an experienced, independent investigator. Both the reduction in ulcer area and the percentage reduction were calculated.
• **Results:** Sixty patients were enrolled into each study, although data for one patient were not available in the pressure ulcer study. There were differences in results at week 1 in favour of the treatment group in both studies, although the results for the two groups in each study were comparable at week 4. Activated charcoal dressing was better tolerated than the control.
• **Conclusion:** These clinical data indicate the potential usefulness of using activated charcoal impregnated with silver in the management of chronic wounds, even at the debridement stage. This dressing may help remove fluids and toxins that impair the healing process.
• **Declaration of interest:** These studies were sponsored by Systagenix Wound Management.


activated charcoal; adsorption; bacteria; toxins; debridement; pressure ulcers; leg ulcers

**J.C. Kerihuel**, MD, Scientific Manager, Vertical, Paris, France.
Email: jc.kerihuel@vertical-pharm.com

Activated charcoal is a charcoal that has been activated to adsorb (bind molecules to its surface) by steaming or heating in a vacuum. Charcoal becomes activated when heated with steam to approximately 1000°C in the absence of oxygen.[1] This process makes charcoal extremely porous. As a consequence, activated carbon has a large pore volume and a large surface area, giving it a unique adsorption capacity.[2] When applied onto a wound, activated charcoal dressings adsorb bacteria, locally released toxins and wound degradation products, thereby promoting wound healing.[3]

The first available dressing of this type was Actisorb (Systagenix Wound Management). Later, silver was added to the charcoal cloth (Actisorb Silver 220) as silver ions have a broad-spectrum antimicrobial effect,[4,5] and so should help kill adsorbed bacteria within the carbon matrix. It is possible that this might help promote healing in stagnating chronic wounds, which have a high bioburden.[6-8]

Two randomised controlled trials, briefly reported in 2003 in *Journal des Plaies et Cicatrisations*, investigated the healing outcomes achieved with Actisorb.[9] Both had similar study designs (open, four-week, parallel group), with one following the use of Actisorb (without silver) on pressure ulcers (PUs) and the other the use of Actisorb Silver 220 on venous leg ulcers (VLUs). Both used a carboxymethylcellulose dressing (hydrocolloid) as the control. This paper describes the methodology and results of the two studies.

The two studies are described separately below. Both studies were approved by the same ethics committee (Comité Consultatif de Protection des Personnes dans la Recherche Biomédiale) at the Hôtel-Dieu University Hospital, Paris, France. All subjects received detailed information about the study protocols and gave written informed consent to participate.

## Method: pressure ulcer study

Six hospitals participated in the PU study. Both inpatients and outpatients were eligible for recruitment into the study.

Inclusion criteria were:
• PUs with an area ranging from 5 to 100cm$^2$
• PUs of less than three months' duration
• PUs graded IIc or IV on the Yarkoni classification[10] — that is, full-thickness ulcers that had not extended down to the bone. This classification system was used throughout the study hospitals to grade PUs, and so was incorporated into the study design.
• PUs considered by investigators to have abundant necrotic tissue and slough (covering ≥50% of the wound surface). (In France, Actisorb Silver 200 can be used as a debriding agent in conjunction with

**Box 1. Secondary outcome: percentage of completely debrided wound**

Actisorb was used in conjunction with sharp debridement to remove the necrotic tissue. One of the secondary outcomes assessed was the percentage of completely debrided tissue — that is, no exudation, no necrotic tissue and <25% of the wound surface covered with slough (a score of 0 on the scale outlined below).

A colormetric scale was used to record the percentage of wound surface covered with necrotic tissue (black), slough (yellow), granulation (red) and re-epithelialisation (pink) tissue. The following were scored at each assessment, according to the scale developed for these two studies:

- Exudation: 0 = none; 1 = mild to moderate; 2 = abundant
- Slough: 0 = <25% of wound area covered with slough; 1 = 25–50% covered; 2 = >50% covered

Necrotic tissue: 0 = none; 1 = <25% of wound area covered; 2 = 25–50% covered; 3 = >50% covered

The total score could range from 0 to 7. A score of 0 was considered to indicate appropriate debridement. Baseline wound characteristics are given in Tables 1 and 2.

At the end of the four weeks, 11 (37.9%) PUs treated with the test dressing were totally debrided, compared with five (16.1%) control-treated PUs (p=0.056); 18 VLUs (60%) treated with the test dressing were totally debrided compared with 17 (56.7%) controls. While these results are of interest, it should be noted that they are attributable to the use of sharp debridement as well as the dressing

sharp debridement if required.)

Main exclusion criteria were:

- Inability to give written consent to participate
- Severe illness
- Pressure ulcers totally covered with necrotic tissue or requiring surgical debridement
- Infected ulcers requiring systemic antibiotics
- Known allergy to the study dressing
- Previous use of Actisorb

One ulcer per patient was included in the study.

### Randomisation

Patients were randomly allocated to either the test dressing (Actisorb) or the control (DuoDerm, ConvaTec).

Randomisation was by blocks of four: identical sealed boxes containing the allocated dressings, gauze and saline were randomly allocated to each patient. The box reference number indicated which study arm the patient had been allocated to, although this was unknown to the patient and investigator. The box reference numbers were verified by a coordinating centre before allocation.

### Intervention

Standardised PU management strategies (regular repositioning and use of pressure-redistributing surfaces) were applied to all patients.

Necrotic tissue and debris were sharp debrided. The wounds were cleansed with sterile saline only, and either the test dressing or the control dressing was then applied. In the case of large wounds, two dressings could be applied side by side. Dressings were impregnated with saline, covered with gauze and secured with a non-compressive bandage. The study protocol stipulated that the dressing should be changed two to three times per week or more frequently in cases of abundant exudation.

The test dressing was applied for four weeks. After four weeks, patients in the treatment group whose ulcers had not healed switched from the test dressing to Adaptic (Systagenix Wound Management). Only results for the first four weeks, when the test dressing was used, are given here. No secondary dressing was used at any stage in the study.

### Assessment

The investigators assessed the patients/wounds once weekly for four weeks, or less if complete wound closure (defined as complete re-epithelialisation) occurred before then.

At each weekly assessment, the wound was traced and photographed, and the exudate level and wound bed characteristics were assessed. Box 1 gives details on the assessment of the wound bed characteristics, which included assessment of the extent of devitalised tissue.

All wound tracings were measured by two independent, experienced clinicians who were unaware of the treatment allocation. Each evaluator twice measured the largest and shortest wound dimensions, and the mean of the two wound axis measurements was used as the final value. Estimation of the wound surface area was based on the sum of the two axes.

All local care was performed and recorded by the same nursing team in each of the participating centres.

## Method: leg ulcer ulcer study

Seven hospitals particpated in this study. Two also participated in the PU study.

Inclusion criteria were:

- Ulcers of primarily venous origin (ankle brachial pressure index >0.7) that were not contraindicated to compression bandaging
- VLUs of ≤12 months' duration
- VLUs with an area ranging from 5 to 100cm$^2$
- VLUs considered by the investigators to have abundant necrotic tissue and slough (covering ≥50% of the wound surface).

Exclusion criteria were:

- Poorly controlled diabetes (in the investigator's opinion)
- Presence of peri-wound eczema
- Severe illness
- Infected ulcers requiring systemic antibiotics

- Known allergy to the study dressing
- Previous use of the test dressing.

One ulcer per patient was included in the study.

### Randomisation

The same randomisation procedure was used as in the PU study, except that the study dressing was Actisorb Silver 220 and the box also contained compression bandaging.

### Intervention

Again, the same protocol was used as for the PU study, except that patients were strongly recommended to wear compression bandage on a daily basis. All patients used the same system: Biflex 16, Thuasne, France. Overall, the investigators considered patient concordance with compression throughout the study to be acceptable in 12 (40%) and 15 (50%) of the patients in the test and control groups respectively.

### Assessment

VLUs were assessed using the same protocol as for the PU study

## Study outcomes

The primary study outcome for both studies was the absolute reduction in wound area ($cm^2$) achieved in the first four weeks of the study, when the test dressing was applied, compared with baseline.

The secondary outcome measure for both studies was the relative (percentage) reduction in wound area compared with baseline. Another secondary outcome measure was the percentage reduction of debrided tissue. Assessment methods and results for this are given in Box 1.

## Statistical analysis

No *a priori* power calculations were performed. Sample sizes were pragmatically determined with the view that 30 patients per group would be sufficient to detect clinically relevant trends in favour of the test dressing.

All analyses used data from the intention-to-treat population (defined as all randomised patients whose wounds were traced in at least one assessment during the first four weeks of the study).

Scale variables are presented as mean ± standard deviation or as median (range).

Absolute and relative changes in wound area were compared between groups at weeks 1, 2, 3 and 4 using the non-parametric Mann-Whitney U test. No adaptation of the alpha risk for repeated testing was used. Ordinal and nominal variables were compared using either the chi-square test or Fisher's exact test. SPS software was used. A p value of less than 5% (<0.05) was considered as indicating statistical significance.

**Table 1. Pressure ulcer study: patients and wound characteristics at baseline**

| | Treatment group (n=29) | Control group (n=30) |
|---|---|---|
| **Demographic data** | | |
| Sex (male/female): No. (%) | 5/24 (17/83) | 9/21 (30/70) |
| Age (years) mean ± SD | 83.2 ± 13.2 | 78.5 ± 16.5 |
| Body mass index: | | |
| • >30 | 3.6% | 10.3% |
| • 20–29 | 89.3% | 62.1% |
| • <19 | 7.1% | 27.6% |
| **Wound characteristics** | | |
| Ulcer location: | | |
| • Sacrum | 4 (13.8%) | 6 (20%) |
| • Heel | 22 (75.9%) | 20 (66.7%) |
| • Other | 3 (10.3%) | 4 (13.3%) |
| Wound duration: | | |
| • >1 month | 15 (51.7%) | 15 (50%) |
| • >3 months | 3 (10.3%) | 1 (3.3%) |
| Wound area ($cm^2$) mean ± SD (median) | 25.3 ± 24.6 (17.5) | 22.6 ± 18.4 (16.0) |
| Pain experienced at dressing change | 19 (65.5%) | 19 (63.3%) |
| Necrotic tissue present | 5 (17.2%) | 4 (13.3%) |
| Slough >50% of wound area | 13 (44.8%) | 17 (56.7%) |
| Strong exudation | 6 (20.7%) | 5 (16.7%) |
| Oedema | 1 (3.4%) | 5 (16.7%) |

## Results: pressure ulcer study

### Patient and wound characteristics

Sixty patients were recruited into the PU study: 29 to the treatment group and 31 to the control group. One patient was not included in the intention-to-treat analysis because her wound tracing was not available for analysis (she died suddenly two days after randomisation). Patients and wound characteristics are presented in Table 1.

In 42 cases (71.2%), the study PU was located on the heel. For the sample as a whole, 29 patients (49.2%) were able to ambulate with or without help, 21 (35.6%) had very limited mobility and nine (15.3%) were bedridden. None of the patients had

**References**

**1** Marsh, H., Rodríguez-Reinoso, F. Activated Carbon. Elsevier, 2006.

**2** Baker, F.S., et al. Activated carbon. Kirk-Othmer Encyclopedia of Chemical Technology 1992; 4: 1015-1037.

**3** Kerihuel, J.C., Charcoal combined with silver for the treatment of chronic wounds. Wounds UK 2009; 5: 3.

**4** Stephen-Haynes, J., Toner, L. Assessment and management of wound infection: the role of silver. Br J Community Nurs, 2007; 12: 3, S6-S12.

**Table 2. Pressure ulcer study: reduction in wound area ($cm^2$)**

| | Treatment group (n=29) | Control group (n=30) |
|---|---|---|
| Week 1 | -2.5 (-22.4–18.4) | 0.0 (-8.8–24.0) |
| Week 2 | -2.8 (-41.2–16.1) | -2.7 (-24.1–24.0) |
| Week 3 | -4.2 (-28.2–11.7) | -1.8 (-24.1–28.7) |
| Week 4 | -4.3 (-31.2–13.8) | -3.1 (-24.1–46.0) |

Results are reported as median (range)

**Table 3. Pressure ulcer study: percentage reduction**

| | Treatment group (n=29) | Control group (n=30) |
|---|---|---|
| Week 1 | -11.7 (-55–130.5) | 0.0 (-85.7–77.4) |
| Week 2 | -25.0 (-73–114.5) | -14.1 (-95–148.1) |
| Week 3 | -30.8 (-72.6–61.6) | -10.3 (-95.6–215.8) |
| Week 4 | -26.9 (-82–97.9) | -18.5 (-100–260.9) |

Results are reported as median (range)

severe dementia and 38 (64.4%) had incontinence problems.

Baseline characteristics (including wound characteristics) were comparable between groups.

### Withdrawals

Fourteen patients (23.7%) withdrew from this study. Seven withdrew from the treatment group for the following reasons:

- Wound stagnation (n=3)
- Intercurrent event (septicaemia) (n=1)
- Other reasons (one death, returned home in two cases) (n=3)

Seven patients also withdrew from the control group:

- Local adverse event (wound infection) (n=1)
- Wound stagnation (n=2)
- Intercurrent events (hip fracture and death) (n=2)
- Wound graft (n=1)
- Other reasons (wish to return home) (n=1)

### Reduction in wound area

The median reductions in wound area ($cm^2$), compared with baseline, reported for both groups at weeks 1–4 are given in Table 2. At week 1, the median reduction in wound area was -2.5$cm^2$ and 0.0$cm^2$ in the treatment and control groups respectively. This was not statistically significant (p=0.255). While a larger median reduction was reported for the treatment group throughout the study period, this does not reach statistical significance.

**Table 4. Pressure ulcer study: local adverse events**

| | Treatment group | Control group |
|---|---|---|
| Maceration/high exudation level | 0 | 2 |
| Wound infection | 1 | 2 |
| Wound aggravation | 0 | 1 |
| Overgranulation | 0 | 1 |
| Eczema | 0 | 1 |
| Pruritus | 1 | 0 |
| Pain | 0 | 0 |
| Skin irritation | 0 | 0 |
| Bleeding at dressing removal | 0 | 0 |

### Percentage reduction

The median percentage reductions in wound size, compared with baseline, reported for both groups at weeks 1–4 are given in Table 3. Again, wound regression was higher at week 1 in the test group but the difference in favour of the test dressing was not statistically significant different (-11.7% versus 0.0). This difference was not maintained throughout the study, with a median reduction of -26.9% reported for the treatment group compared with -18.5% for the control group at week 4.

### Dressing tolerability

Local adverse events reported by investigators are presented in Table 4. Two patients in the treatment group reported adverse events (6.9%) compared with seven in the control group (161.1%).

## Results: venous leg ulcer study

### Patient and wound characteristics

Sixty patients were recruited into the VLU study, 30 to the test dressing group and 30 to the control group. Patient and wound characteristics are given in Table 5.

Of the patients recruited to the VLU study, eight (13.8%) had diabetes. For the group as a whole, 16 (26.7%) had a history of venous thrombosis, and 27 (45%) were already being treated with compression at inclusion. Sixteen (53.3%) and 19 (63.3%) patients given the test and control dressing respectively had a history of ulceration.

**5** Leaper, D.J., Silver dressings: their role in wound management. Int Wound J 2006; 3: 4, 282-294.

**6** Martin, J.M., Zenilman, J.M., Lazarus, G.S. Molecular microbiology: new dimensions for cutaneous biology and wound healing. J Invest Dermatol 2010; 130: 1, 38-48.

**7** Singh, V.A., Barbul, A. Bacterial biofilms in wounds. Wound Repair Regen 2008; 16: 1, 1.

**8** Xu, L., McLennan, S.V., Lo, L. et al., Bacterial load predicts healing rate in neuropathic diabetic foot ulcers. Diabetes Care 2007; 30: 2, 378-380.

**9** Kerihuel, J.C., Dujardin-Detrez, S. Actisorb Plus 25, a review of its clinical experience based on more than 12 000 various wounds. JPC 2003; 8: 39, 3-7.

**10** Yarkony, G.M. Pressure ulcers: a review. Arch Phys Med Rehabil 1994; 75: 8, 908-917.

**11** Mulligan, C.M., Bragg, A.J. O'Toole, O.B. A controlled comparative trial of Actisorb activated charcoal cloth dressings in the community. Br J Clin Pract, 1986; 40: 4, 145-148.

**12** Wunderlich, U., Orfanos, C.E. Treatment of venous leg ulcers with silver-impregnated xero dressings. Hautartz 1991; 42: 446-450.

**13** White, R.J. A charcoal dressing with silver in wound infection: clinical evidence. Br J Comm Nurs 2001; 6: 12 (Suppl), 2.

**14** Du, X.N., Niu, Z., Zhou, G.Z., Li, Z.M. Effect of activated charcoal on endotoxin adsorption. Part I. An *in vitro* study. Biomater Artif Cells Artif Organs 1987; 15: 1, 229-235.

continued opposite

**Table 5. Leg ulcer study: patients and wound characteristics at baseline**

| | Treatment group (n=30) | Control group (n=30) |
|---|---|---|
| **Demographic data** | | |
| Sex (male/female): No. (%) | 10/20 (33/67) | 11/19 (37/63) |
| Age (years) mean ± SD | 77.6 ± 12.9 | 76.0 ± 12.2 |
| Body mass index: | | |
| • >30 | 28.0% | 32.1% |
| • 20–29 | 60.0% | 60.7% |
| • ≤19 | 12.0% | 7.1% |
| **Wound characteristics** | | |
| Aetiology: | | |
| • Venous | 22 (73.3%) | 21 (70.0%) |
| • Arterial component | 8 (26.7%) | 9 (30.0%) |
| Wound duration: | | |
| > 1 month | 10 (33.3%) | 11 (36.7%) |
| > 3 months | 9 (30.0%) | 1 (46.7%) |
| Wound area ($cm^2$) mean ± SD (median) | 18.1 ± 18.2 (12.1) | 17.5 ± 24.4 (8.2) |
| Pain experienced at dressing change | 16 (53.3%) | 13 (43.3%) |
| Necrotic tissue present | 2 (6.7%) | 2 (6.7%) |
| Slough >50% of wound area | 0 (0.0%) | 0 (0.0%) |
| Strong exudation | 0 (0.0%) | 0 (00.0%) |
| Oedema | 13 (43.3%) | 9 (30.0%) |

Baseline characteristics (including wound characteristics) were comparable between groups.

### Withdrawals

Seven patients (11.7%) withdrew from the VLU study. Only one patient withdrew from the test dressing (hospitalisation for heart failure). Six patients withdrew from the control group for the following reasons:

- Local adverse event (eczema) (n=2)
- Intercurrent event (death) (n=1)
- Other reasons: withdrawal of consent (n=2) and discharge home (n=1)

**Table 6. Leg ulcer study: reduction in wound area ($cm^2$)**

| | Treatment group (n=30) | Control group (n=30) |
|---|---|---|
| Week 1 | -2.2 (-21.2–5.0) | -0.1 (-23.4–18.3) |
| Week 2 | -3.2 (-27.7–5.2) | -1.3 (-49.5–4.5) |
| Week 3 | -4.5 (-26.4–14.0) | -2.3 (-53.3–18.4) |
| Week 4 | -4.5 (-30.9–22.5) | -3.5 (-53.3–18.5) |

Results are reported as median (range)

**Table 7. Leg ulcer study: percentage reduction**

| | Treatment group (n=30) | Control group (n=30) |
|---|---|---|
| Week 1 | -16.4 (-100–80) | -0.9 (-84–82.9) |
| Week 2 | -18.7 (-100–61.5) | -14.6 (-96.4–10) |
| Week 3 | -29.5 (-100–156.4) | -24.3 (-100–50) |
| Week 4 | -35.6 (-100–182.1) | -40.9 (-100–308.3) |

Results are reported as median (range)

### Reduction in wound area

The median reductions in wound area ($cm^2$), compared with baseline, reported for both groups at weeks 1–4 are given in Table 6. At week 1, the median reduction was -2.2$cm^2$ and -0.1$cm^2$ for the treatment and control groups respectively (p=0.066) and reached -4.5$cm^2$ and -3.5$cm^2$ respectively at week 4.

### Percentage reduction

The median percentage reductions in wound size, compared with baseline, reported for both groups at weeks 1–4 are given in Table 7. At week 1, median reductions reported were -16.4% and -0.9% for the treatment and control groups respectively (p=0.074). By week 4, the percentage reductions reported were similar for the both groups: -35.6% versus -40.9%.

### Dressing tolerability

Local adverse events reported by the investigators are presented in Table 8. Five patients reported adverse events in the treatment group (13.3%), compared with 20 in the control group (33.3%).

## Discussion

These results support those of other studies performed on Actisorb. In Mulligan et al.'s RCT, 101

**Table 8. Leg ulcer study: local adverse events**

| | Treatment group | Control group |
|---|---|---|
| Maceration/high exudation level | 0 | 9 |
| Wound infection | 1 | 1 |
| Wound aggravation | 2 | 0 |
| Overgranulation | 0 | 0 |
| Eczema | 0 | 5 |
| Pruritus | 0 | 0 |
| Pain | 1 | 1 |
| Skin irritation | 1 | 3 |
| Bleeding at dressing removal | 0 | 1 |

subjects with ulcers were treated with either Actisorb (without silver) or a control (any other dressing regarded as most appropriate by investigators) for six weeks, unless healing occurred sooner.[11] Compared with baseline, the mean percentage reduction in wound area was statistically significant for the treatment group (28.7% ± 3.9%) versus the control (11.7% ± 6.8%). In addition, the test dressing was found to be statistically superior in terms of reducing exudate levels, malodour and oedema (p=0.005).

Wunderlich et al., in their RCT, randomised 40 patients with chronic VLUs to receive treatment with either Actisorb Silver 220 or zinc paste for six weeks. Results showed that use of the test dressing resulted in a statistically significant reduction in wound area when compared with the controls (p<0.05), with 6/19 evaluated patients in the treatment group healing fully versus 2/19 evaluated patients in the control group.[12]

Evidence from non-controlled studies, large population surveys and case studies also support the clinical benefit of using Actisorb dressing in various clinical situations.[9,13]

Furthermore, in the present study, patients in the treatment group reported fewer dressing-related adverse events. The most frequent adverse event reported in the control groups was maceration/high exudate level, but this was not reported in either of the two treatment groups. This suggests that, by binding toxins, Actisorb helps to promote healing.

Activated charcoal has been reported to remove endo- and exotoxins from fluid *in vitro*.[14] Other *in vitro* studies have found that, when submerged in a milieu enriched with *Escherichia coli*, activated charcoal removed 90–95% of this toxin.[15,16]

In *in vitro* and *in vivo* experiments using a murine model of gut-derived endotoxemia, activated charcoal was able to bind enotoxin in both test methods.[17] It also has been shown that activated charcoal can adsorb bacteria, viruses and various other biochemicals *in vitro* and *in vivo*.[18,19] Additionally, *ex vivo* and *in vitro*, activated charcoal filters has been found to filter inflammatory chemokines and cytokines such as IL-8 or TNF-$\alpha$ from blood.[20-22]

When silver is incorporated in the activated charcoal matrix, it is not released. However, an *in vitro* study found that the silver killed the bacteria adsorbed by the activate charcoal, suggesting that it will reduce the bioburden.[23] Verdu Soriano et al. clearly confirmed that Actisorb Silver 220 substantially reduced bacterial burden.[24]

### Study limitations

While following the same methodology, including blind evaluation of wound tracings, these studies had small sample size, so were underpowered. Nevertheless, it is of interest that both indicated that the test dressing may help to promote healing, regardless of the wound aetiology.

## Conclusion

Experimental and clinical data indicate the potential usefulness of using activated charcoal impregnated with silver in the management of chronic wounds, even at the debridement stage. This type of dressing may help remove from the wound bed fluid and toxins that impair the healing process. ■

**15** Nolan, J.P., McDevitt, J.J., Goldman, G.S., Bishop, C. Endotoxin binding by charged and uncharged resins. Proc Soc Exp Biol Med 1975; 149: 3, 766-770.

**16** Maitra, S.K., Yoshiawa, T.T., Guze, L.B., Schotz, M.C. Properties of binding of *Escherichia coli* endotoxin to various matrices. J Clin Microbiol 1981; 13: 1, 49-53.

**17** Ditter, B., Urbaschek, R., Urbaschek, B. Ability of various adsorbents to bind endotoxins *in vitro* and to prevent orally induced endotoxemia in mice. Gastroenterology 1983; 84: 6, 1547-1552.

**18** Drucker, M.M., et al., The effect of attapulgite and charcoal on enterotoxicity of *Vibrio cholerae* and *Escherichia coli* enterotoxins in rabbits. Infection 1977; 5: 4, 211-213.

**19** Naka, K., Watarai, S., Tana Inoue, K. et al., Adsorption effect of activated charcoal on enterohemorrhagic *Escherichia coli*. J Vet Med Sci 2001; 63: 3, 281-285.

**20** Howell, C.A., Sandeman, S.R., Philips, G.J. et al. The *in vitro* adsorption of cytokines by polymer- pyrolysed carbon. Biomaterials 2006; 27: 30, 5286-5291.

**21** Cole, L., Bellomo, R., Davenport, P. et al., The effect of coupled haemofiltration and adsorption on inflammatory cytokines in an *ex vivo* model. Nephrol Dial Transplant 2002; 17: 11, 1950-1956.

**22** Sandeman, S.R., Howell, C.A., Mikhalovsky, S.V. et al., Inflammatory cytokine removal by an activated carbon device in a flowing system. Biomaterials 2008; 29: 11, 1638-1644.

**23** Müller, G., Winkler, Y., Kramer, A. Antibacterial activity and endotoxin-binding capacity of Actisorb Silver 220. J Hosp Infect 2003; 53: 3, 211-214.

**24** Verdú Soriano, J., Rueda López, J. et al. Effects of an activated charcoal silver dressing on chronic wounds with no clinical signs of infection. J Wound Care 2004; 13: 10, 419-423