

THE CLINICAL USE OF PEDOBAROGRAPHY

J. HUGHES

Several years' experience with different pedobarograph systems has demonstrated that foot pressure measurements can be used as a clinical tool. This tool can aid a surgeon's decision making, but it cannot be used diagnostically in isolation from clinical data. The clinical uses are both direct and indirect. The direct uses can be summarized as follows : to assess the effect of treatment by examination before and after a surgical procedure ; to monitor progress by means of sequential measurements and to design and assess the effectiveness of orthoses. These uses are demonstrated with reference to a number of studies of normal subjects compared to patient groups using the dynamic pedobarograph. Indirect uses come from the growing body of knowledge emerging from laboratories using this equipment for research. This is helping us to understand weightbearing foot function both in health and disease. Clinicians intending to invest in the equipment can also obtain useful guidelines on the reliability of the different systems and measurements and best ways to standardize methodology. Some examples of these indirect uses are illustrated with results from studies using the dynamic pedobarograph and the EMED F system.

Keywords : pedobarography.

Mots-clés : pédobarographie.

INTRODUCTION

Many different methods have been used to measure the pressure distribution under the foot. The first one to be documented was a static footprint system attributed to Forstall in 1925 (5). The subject stood on paper on a wire net suspended over an inked mat. Areas of the foot taking the

greatest pressure stretched this net, pressed harder onto the ink and made a darker impression on the paper. The first dynamic method also used footprints and was devised by Morton (15) in 1930. The subject walked along a long inked mat with triangular corrugations placed over paper. The prints produced parallel lines whose width was proportional to the pressure.

Since then instrumented optical methods, force plates and load cells, and insoles and pressure pads have been used to study and analyze subjects' foot pressure distribution. Many of these systems have not emerged from the research laboratory into clinical use, but the systems of the most recent generation are more reliable and are now commercially available, making their use in clinics feasible. However, as the techniques are new, and the systems still evolving, an element of research must therefore accompany their clinical use in order to document results and standardize methodology. Each system must be tested before being used to assess patients in order to measure its reliability and efficiency. Lack of this analytical approach and attempts to use the equipment diagnostically have led some centers to doubt the usefulness of the systems.

There are three main direct clinical uses of pedobarography in the clinic. The first of these is the assessment of the effect of treatment. Clinicians may argue that they do not need expensive equip-

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ment to tell them which areas of the foot are subject to high pressure. This is, of course, true, but no other technique can accurately quantify this pattern or demonstrate the redistribution of the pressure due to the treatment. The second use is to monitor the progress of individuals or groups of patients by comparison of sequential recordings which can be filed in the patient's notes. The third use is to help in the designing and assessment of orthoses. This use will be enhanced by in-shoe measuring devices which are not yet as sophisticated as barefoot techniques and are not yet ready to emerge from the research laboratory.

There are also indirect ways in which this equipment can be used by the clinicians by benefiting from the output of research laboratories in which the equipment is used. This can help the understanding of weightbearing foot function in health and disease and can help to assess new equipment and standardize methodology.

MATERIALS AND METHODS

The two systems used in the studies which are described to illustrate the uses of pedobarography are the dynamic pedobarograph (PBG) with the Sheffield system of analysis and the EMED F (EMED) system*. The PBG is an optical system which has been used most in the United Kingdom but is now available in the USA. It has never become very popular but has been well documented in the literature (4, 8). Its pressure measurements are prone to slight error (6), but its main forte is its resolution which is almost infinite. Figure 1

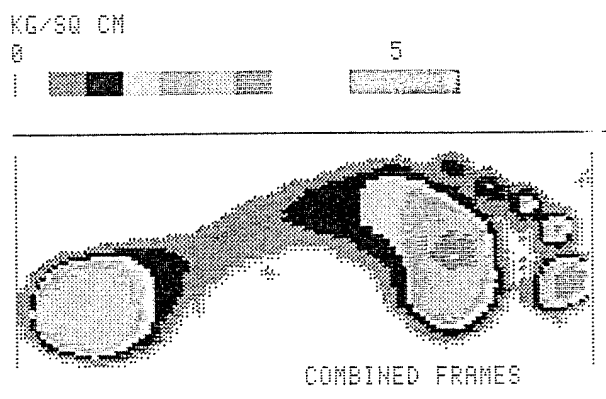


Fig. 1. — Black and white picture of the colored combined frames picture from the dynamic pedobarograph.

shows a black and white picture of a combined frames print from the colored PBG printout. This shows the highest pressure reached by each part of the foot and shows the overall pressure pattern. Increasing pressure can be seen by the decreasing contours, and the highest pressure is the small light area under the second metatarsal head. The scale is in kg/cm^2 . Measurements have been translated into kilopascals in the analysis.

The EMED F is a force plate with discrete capacitance transducers which is already popular (20). It has good accuracy but less good resolution, though more recent versions, for example the EMED SF, have better resolution and frequency response. Figure 2 shows a black and white picture of the colored maximum pressures plot from the EMED F printout. This is the same as a combined frames picture. The different contours cannot be seen as clearly as in fig. 1 due to the different colors used, but this figure shows the difference in resolution between the two systems.

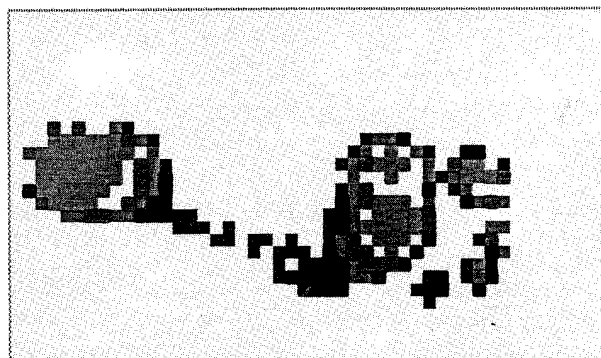


Fig. 2. — Black and white picture of the colored maximum pressure plot for the EMED F system.

Both the systems used allow computer storage of the pressure patterns, and each has software which allows areas of interest to be selected for further analysis. Twelve areas of interest were identified on all the recordings. These correspond with the heel, the five metatarsal heads, the five toes and the base of the fifth metatarsal. The mean of the three walks for each area for each foot was used in further analysis.

* The dynamic pedobarograph can be obtained from the following sources : In Europe : The Commercial and Industrial Development Bureau, University of Sheffield, Western Bank, Sheffield S10 2TN, England ; In the USA : Biokinetics Inc., 5413 West Cedar Lane, Unit 103C, Bethesda, Maryland, 20814, USA.

The EMED F system can be obtained from NOVEL GmbH, Beichstrasse, 8, 8000 Munich 40, Germany.

All the studies described have used the same method. Each subject/patient walked three times over the equipment with each foot. The walkway was more than 5 metres, allowing at least one and a half strides before measurement. The measuring surface was not disguised, but time was given to practice walking normally over the walkway, and any uncharacteristic walks were discarded. Clinical examination accompanied each assessment. In the case of the normal subjects this was to rule out disease or deformity which may have affected the results, and in the case of the patients this was to ensure that they fitted the study criteria. Analysis techniques examined the left and right feet separately, as using the mean of the left and right feet would produce a misleading average pattern. Also the statistical procedures used required the observations to be independent of each other which is true of measurements from different people, but not necessarily true of left and right feet from a single individual (16).

INDIRECT CLINICAL USES

The first indirect use of the equipment is to learn from the mounting bank of data about normal subjects and to make comparisons among large groups of similar patients. This can help in the understanding of normal foot function. A number of studies of "normal" subjects using different systems have been reported, both static measurements (3, 17) and dynamic measurements (14, 18, 19).

The next three illustrations demonstrate the results from a study of 160 subjects without evidence of foot deformity or disease. The full results from these studies can be found in refs. 10 and 12.

Figure 3 shows median contact times as a proportion of stance phase. The points are for the left and right feet for each area of the foot — the heel, the metatarsal heads, the toes and the base of the fifth metatarsal. The bars mark the 5th and 95th percentiles showing the spread of the data. The metatarsal region of the foot is in contact longer than any other region of the foot, and although there is greater variability under the toes, they are also in contact for more than 50% of stance phase. Figure 4 shows the median peak pressure distribution in the same format as contact time. This is only for the 100 adult subjects as

peak pressure for the whole group was shown to be related to weight. The mean pattern of loading across the forefoot shows the highest pressures to be under the central metatarsal heads with decreasing pressure both laterally and medially. The pressure under the toes decreases from medial to lateral but is not insignificant, as some authors have suggested (14).

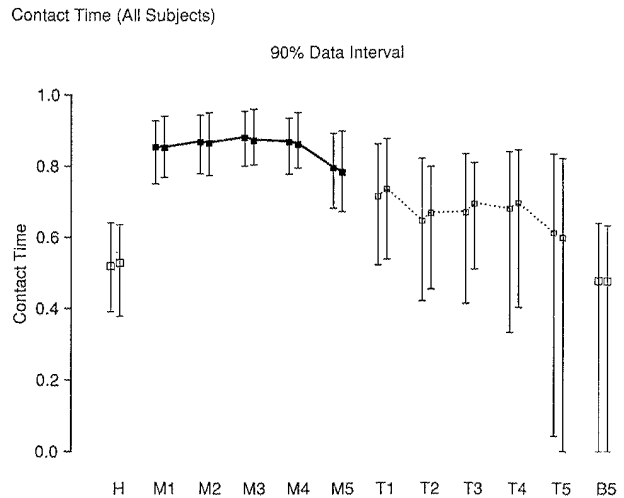


Fig. 3. — Median and 90% data interval for the contact time as a proportion of stance phase for 160 normal subjects measured on the dynamic pedobarograph. The two dots indicate left and right feet for the 12 areas of the foot. H = Heel, M1-5 = 5 metatarsal heads, T1-5 = the five toes and B5 = base of the fifth metatarsal.

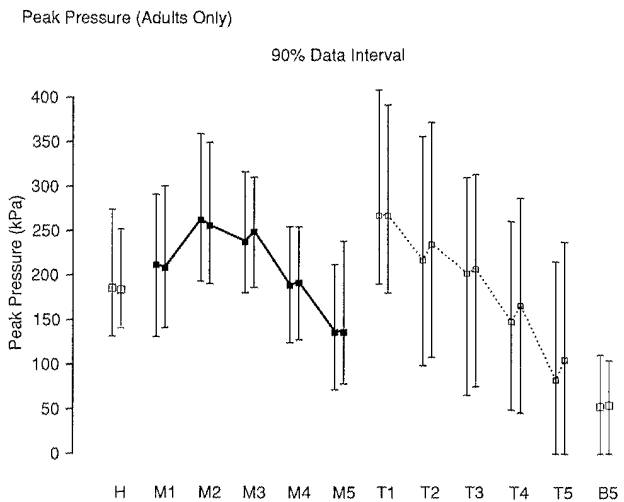


Fig. 4. — Median and 90% data interval for the peak pressures for 100 normal adult subjects measured on the dynamic pedobarograph. The two dots show subjects' left and right feet for the same 12 areas shown in fig. 3.

While this type of analysis gives the median distribution, it is clear that individuals differ significantly but can be grouped depending on the pattern across the forefoot (9). Figure 5 shows the four groups found objectively by cluster analysis. Each set of dots represents the pressure under a metatarsal head from the first to the fifth. Of particular clinical interest is that the dominance of the first ray differs normally, and surgery of this area of the foot may have a different result depending on the patient's normal pattern.

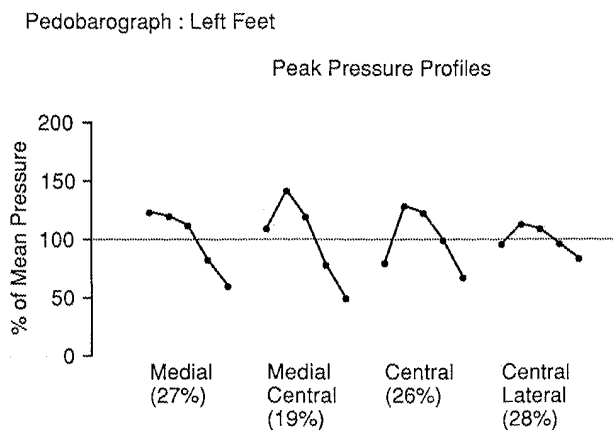


Fig. 5. — The peak pressure profiles for the four groups defined by cluster analysis for results of 100 normal adults measured on the dynamic pedobarograph.

Close comparison of these results with the other studies referred to above reveals differences, but many of these can be explained by knowledge of the way in which the systems operate and the individual characteristics such as resolution, frequency response and hysteresis. A comparison of two large studies using commercially available equipment has confirmed differences in peak pressure/force and contact time and similarities in the patterns of pressure distribution (13). It is therefore not necessary for all centers to undertake such studies.

These studies can also be used to help to understand the foot in disease by comparison with large groups of similar patients. The obvious example of this is the study of patients with diabetes. Several studies have shown that compared with normal, patients with diabetes show increased

peak pressure under the metatarsal heads (2), and those with neuropathy also show decreased peak pressure and contact time under the toes (7). It has been suggested that foot pressure measurement can be a sensitive measure of early neuropathy.

Research carried out in the laboratory can also help clinicians by pointing to the most effective ways of using the equipment. One example of this is a study of repeatability carried out using the EMED F system. This study assessed 25 walks at 3 different speeds for the right feet of ten asymptomatic subjects (11).

Results of this study show that total force and peak pressure increase linearly with an increase in speed. The clinical significance of this is that follow-up-recordings should always be made at a walking speed similar to that of the first assessment, and therefore walking speed should always be documented. These data were also analyzed to assess the reliability for one walk and the mean of two to twenty-five walks. This is of particular significance for clinical measurements as some handicapped patients cannot walk long distances. A mean of three walks was shown to give excellent reliability for most variables measured, but if only a single walk is possible then the most reliable measurements are peak pressure and total force.

CLINICAL USES

Assessing the effect of treatment

Use of the equipment to measure the effect of treatment on an individual patient is demonstrated in fig. 6. This shows the combined frames printout for a patient with rheumatoid arthritis pre- and postoperatively for forefoot surgery. The operation was an excision of the lateral four metatarsal heads and fusion of the great toe. Preoperatively he showed the classic features of a patient with chronic rheumatoid arthritis: increased peak pressure under the metatarsal heads and absent lesser toe function. Postoperatively the change resulting from the operation was a complete redistribution of pressure in the forefoot.

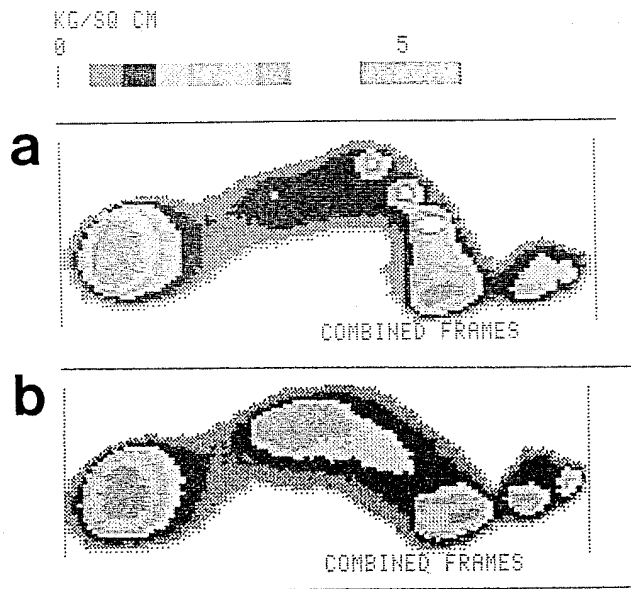


Fig. 6. — Dynamic pedobarograph combined frames picture of a patient with rheumatoid arthritis a) before and b) after forefoot reconstruction surgery.

Monitoring progress

Monitoring the progress of patients is an invaluable clinical tool. Records can be taken regularly and stored in the chart to show exactly how the patient walked on each occasion. This use is demonstrated by another study of patients with rheumatoid arthritis, but this time early disease. The measurements started within 2 years of disease onset, and they were then measured every 6 months for 2 years. Figure 7 shows the first five combined frames picture records of a single patient, and the reader can see the progressive increase in peak pressure under individual metatarsal heads and the decrease in toe function with time. The most marked changes can be seen between the first and third assessments. A group of 44 patients' first assessments compared to normal showed a statistically significant decrease in peak pressures and contact times under the toes and a trend towards increasing pressure under the metatarsal heads even at this early stage in the disease.

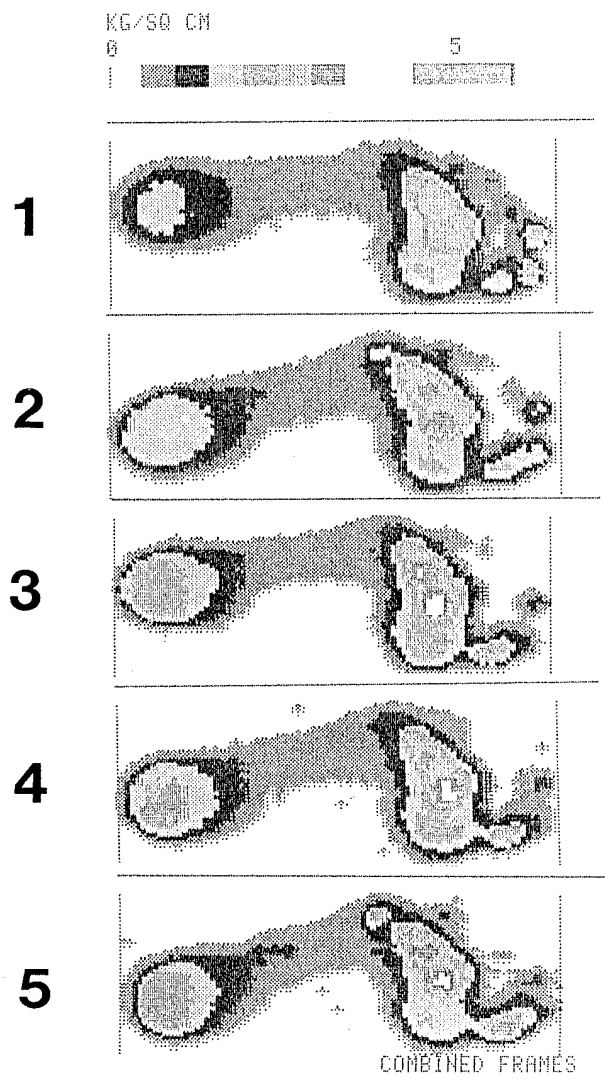


Fig. 7. — Dynamic pedobarograph combined frames pictures of a single patient with early rheumatoid arthritis. The numbers 1 to 5 show first to fifth assessments at 6 monthly intervals.

Design and assessment of orthoses

Foot pressure-measuring equipment can be used to test the effectiveness of orthoses even though it is apparently testing the wrong interface, the orthosis and the plate and not the foot. Figure 8 shows the same subject walking barefoot and on 4-mm PPT[®]*, and shows that the pressures are

* Registered trade name for a poromeric substance used for making insoles. Manufactured by Langer, Stoke on Trent.

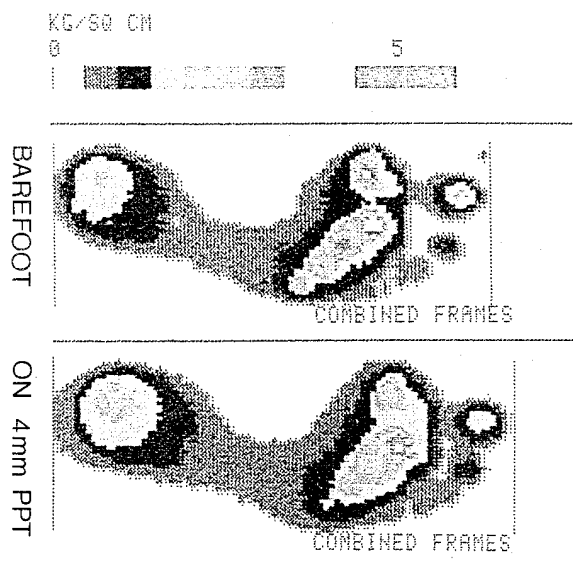


Fig. 8. — Dynamic pedobarograph combined frames pictures of a patient walking barefoot and on a sheet of 4-mm PPT® to show uniform pressure reduction from a homogeneous sheet.

reduced uniformly. Barefoot pressure measurements may be compared to measurements taken with a soft orthosis strapped to the foot, and the redistribution of pressure assessed. This technique has been used to assess the wear characteristics of different materials used to make identical insoles (1).

Clinicians investing in this equipment should locate the device near the clinic to facilitate the clinical input into the examination. When possible one member of the team should be given overall responsibility for taking the measurements and following the patients; otherwise this may be neglected in a busy practice.

CONCLUSIONS

This paper demonstrates the clinical usefulness of foot pressure measurement to clinicians. This use, however, is not as straightforward as a diagnostic tool, rather provides an objective measurement that can add a dynamic component to a clinical examination.

Acknowledgements

I would like to thank Professor Leslie Klenerman of the Royal Liverpool Hospital for his support and clinical input into all the studies described.

I would also like to acknowledge Peter Clark of the Department of Medical Physics, Royal Postgraduate Medical School, Hammersmith for his work on the statistics for the studies described. Full statistical analysis is provided in the papers referred to.

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SAMENVATTING

J. HUGHES. Klinisch gebruik van de pedobarograaf.

Meerdere jaren ervaring met pedobarografen, van verschillende types, hebben aangetoond dat de meting van de voetdruk klinisch significant is. Deze techniek kan behulpzaam zijn bij het stellen van chirurgische indicaties, maar mag niet afzonderlijk gebruikt worden in de diagnostiek, los van het klinisch onderzoek.

De klinische gebruiken zijn én direct én indirect. Het direct gebruik kan als volgt samengevat worden: ter evaluatie van het resultaat van een behandeling met pre- en postoperatief onderzoek, ter evaluatie van de evolutie d.m.v. opeenvolgende metingen en ter evaluatie van de doelmatigheid van orthesen. Deze verschillende gebruiken zullen gedocumenteerd worden aan de hand van meerdere studies waarbij de gegevens verzameld, bij dynamisch pedografisch onderzoek van normale en abnormale voeten, vergeleken worden.

Het indirect gebruik resulteert van de steeds groeiende kennis, verzameld bij laboratoriumstudies, waarbij deze apparatuur gebruikt werd. Deze studies helpen bij de benadering van de biomechanica van de voetbelasting bij al dan niet normale patiënten. De clinicus die in dit materiaal wenst te investeren, kan eveneens richtlijnen bekomen i.v.m. de betrouwbaarheid van de verschillende systemen en middelen om tot een standardisatie te komen. Enige voorbeelden van deze indirecte gebruiken worden geïllustreerd met de resultaten,

bekomen met de dynamische pedobarograaf en met het EMED F systeem.

De dynamische pedobarograaf kan bekomen worden: in Europa, bij The Commercial and Industrial Development Bureau – University of Sheffield, Western Bank, Sheffield S10 2TN, U.K.; in de Verenigde Staten, Biokinetics Inc., 5413 West Cedar Lane, Unit 103C, Bethesda, Maryland 20814, U.S.A.: het EMED F systeem wordt geleverd door NOVEL GmbH, Beichstrasse 8 – 8000 Munich 40 – Duitsland.

RÉSUMÉ

J. HUGHES. Emploi clinique du pédobarographe.

Après de nombreuses années d'emploi de différents systèmes de pédobarographie, il est établi que les mesures de la pression plantaire peuvent être utilisées en clinique. Ce moyen auxiliaire peut contribuer, à l'indication chirurgicale, mais ne peut être utilisé de manière isolée, sans confrontation avec la clinique.

L'usage clinique est à la fois direct et indirect. L'usage direct est avant tout la comparaison des données avant et après traitement chirurgical, les progrès d'un traitement constatés à l'aide de mesures successives et l'évaluation de l'efficacité des orthèses. Les auteurs documentent ces usages, en se référant à des études de sujets normaux et de sujets pathologiques, soumis à des mesures pédobarographiques dynamiques.

L'usage indirect aboutit à un faisceau de connaissances, toujours plus important, résultant des travaux de laboratoire. Ces données permettent de mieux comprendre la biomécanique du pied sain ou malade. Les cliniciens qui désirent investir dans cet équipement, peuvent obtenir des données utiles quant à la fiabilité des différents systèmes de mesure et des meilleurs techniques de standardisation. Quelques exemples de l'usage indirect sont présentés avec des résultats d'études, utilisant le pédobarographe dynamique et le système EMED F. Le pédobarographe dynamique est livrable en Europe: par The Commercial and Industrial Development Bureau – University of Sheffield, Western Bank, Sheffield S10 2TN, U.K.; aux États-Unis par Biokinetics Inc., 5413 West Cedar Lane, Unit 103C, Bethesda, Maryland 20814, U.S.A.: le système EMED F est fournis par: NOVEL GmbH, Beichstrasse 8 – 8000 Munich 40 – Allemagne.