Diffuse Reflectance Near-Infrared Spectroscopy as a Nondestructive Analytical Technique for Polymer Implants

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Abstract □ A near-infrared spectroscopic method to quantify drugs or excipients within polymeric matrixes is proposed. Cylindrical implants were fabricated by a melt-mold technique containing various ratios of poly(ϵ-caprolactone) (PCL) and poly(ethylene glycol) (PEG) and various loadings of lomefloxacin HCl with a constant ratio (70:30 w/w) of PCL/PEG. Near-infrared (NIR) spectra were obtained on intact sections of larger implants using a Foss NIRSystems Model 5000 monochrometer equipped with a Rapid Content Analyzer. Spectral data were treated with second derivative transformation followed by linear regression and PLS to obtain correlation with lomefloxacin or PEG content. Lomefloxacin content was separately determined by UV analysis (287 nm) using a validated extraction procedure. The NIR method was tested by comparing predicted loadings of test implants with either theoretical values based on weight (PEG) or with UV analysis results (lomefloxacin). Second derivative spectral values at particular wavelength ratios (PEG, 2064 nm/1698 nm; lomefloxacin, 2172 nm/2226 nm and 1824 nm/1862 nm) yielded linear results for PEG or lomefloxacin content. PEG content determined by NIR spectroscopy was in excellent agreement with theoretical content. Lomefloxacin content determined by NIR spectroscopy was also in excellent agreement with UV analysis. NIR analysis is interpreted through the use of corresponding mid-infrared spectral data.

Introduction

Polymeric drug delivery systems such as implants and microspheres are finding widespread use in drug delivery. Quantitative analysis of excipients or active ingredients within these dosage forms usually involves destructive extraction procedures followed by an assay, typically HPLC or UV spectroscopy. In cases where only small amounts of drug are available, as in early formulation development, or in cases where dose uniformity is an issue, a nondestructive analytical technique would be useful, allowing subsequent use of the dosage form.

Near-infrared (NIR) spectroscopy is a rapid and nondestructive analytical tool which is gaining acceptance in the pharmaceutical industry as a technique for qualitative and quantitative analysis. NIR applications in the pharmaceutical industry include qualitative identification of raw materials,[1,2] quantitative analysis of drug content in tablets and powder blends,[3−10] determination of moisture content,[11−16] detection of degradation products within solid formulations,[17] and determination of crystallinity.[18] Although quantitative analysis of drugs and excipients has been demonstrated for intact tablets, NIR spectroscopy has not been utilized in quantitative analysis of polymeric dosage forms.

Polymeric dosage forms are often used to provide sustained release of various pharmaceutical entities. When the polymer acts as a solid matrix, the rate of release may be controlled by addition of inert, water-soluble excipients such as poly(ethylene glycol) or sodium chloride. These excipients rapidly dissolve and release upon exposure to water, increasing the effective diffusion coefficient and the release rate of the drug. Because the rate of release is related to the quantity of these pore-forming excipients as well as the quantity of drug in the system, it is important to be able to assess both the quantity and uniformity of these excipients within a polymeric dosage form. The application of NIR spectroscopy for quantitation of excipients and actives within polymeric drug delivery systems would provide a rapid and nondestructive alternative to other analytical techniques. This work investigates the use of diffuse reflectance near-infrared spectroscopy as a nondestructive analytical tool for quantifying poly(ethylene glycol) and lomefloxacin hydrochloride within intact polymer implants.

Experimental Section

Materials—Poly(ϵ-caprolactone) flakes (Scientific Polymer Products Inc., Ontario, NY), poly(ethylene glycol) 600 NF (Union Carbide, Danbury, CT, Lot 578269), and lomefloxacin HCl (G. D. Searle, Skokie, IL., Lot NA007) were used as received. Methylene chloride (Fisher Scientific, Lot #963694), 0.1 N hydrochloric acid (Fisher Scientific, Lot #924316-24), and distilled water were used in the extraction procedure as received. Borosilicate glass disposable culture tubes were used as received for fabrication of implants.

Poly(ϵ-caprolactone)/Poly(ethylene glycol) Implant Preparation—Poly(ϵ-caprolactone) (PCL) and poly(ethylene glycol) (PEG) (0, 5, 10, 15, 20, 25, and 30% w/w) were placed in a 20 mL glass scintillation vial. The materials were melted by placing the vial in a water bath at 75 °C. Upon melting, the two phases were thoroughly mixed with an overhead mixer to ensure uniform dispersion of PEG within the polymer melt. The resulting dispersion was transferred to a 10 mL Becton-Dickenson syringe and injected into precut 5 mm diameter borosilicate tubes. After cooling to room temperature, the implants were removed from the tubes and stored in a vacuum desiccator until use. Implants containing 12.5% and 22.5% w/w PEG were formed using the procedure described for use in validating the near-infrared standard curve.

Poly(ϵ-caprolactone)/Poly(ethylene glycol)/Lomefloxacin Hydrochloride Implant Preparation—Implants containing lomefloxacin HCl were prepared using PCL and PEG 600 at a constant weight ratio of 70:30. After complete dispersion of PEG within the polymer melt, powdered lomefloxacin HCl (5, 10, 15, 20, and 25% w/w) was slowly added with continuous agitation from an overhead mixer to ensure uniform dispersion of drug. The resulting dispersion was injected into the precut borosilicate tubes,

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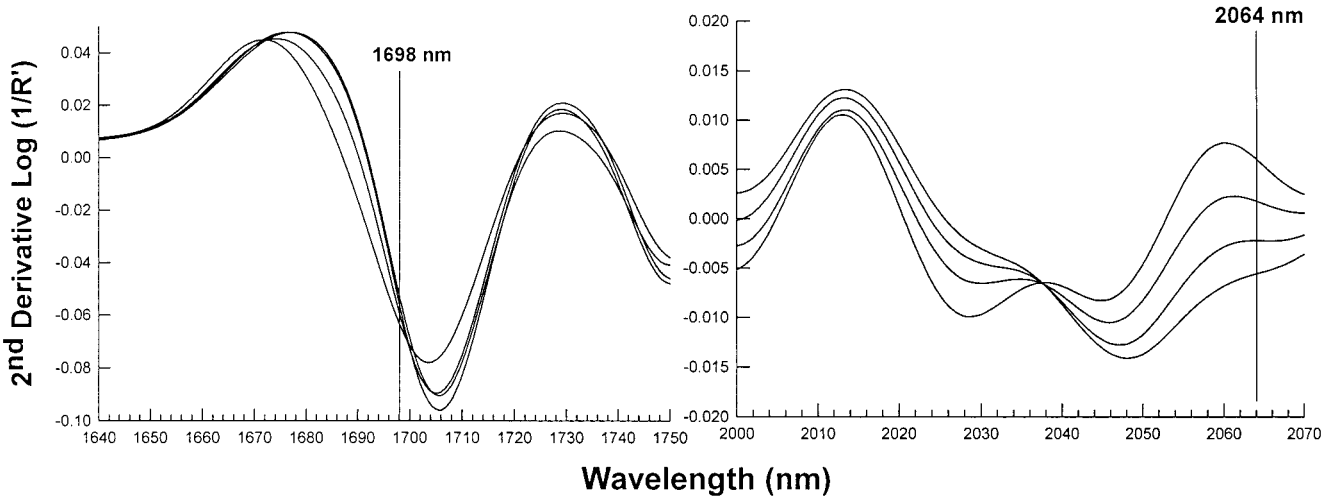

Figure 1—Expanded second derivative NIR spectra for implants containing various poly(ethylene glycol) (PEG) contents. PEG contents from top to bottom at 2064 nm are 0, 10, 20, and 30% w/w PEG 600; the normalizing wavelength (1698 nm) is indicated.

cooled to room temperature, removed from the tubes, and stored in a vacuum desiccator.

Near-Infrared Analysis—Two implants from each batch were selected at random. A surgical scalpel was used to cut two 5 mm slices from each implant. Each slice was placed on a glass cover slip and placed in the center of the sample holder using the iris centering device. Both radial surfaces from each slice were scanned in reflectance mode from 1100 to 2500 nm using a Foss NIRSystems Model 5000 monochrometer equipped with a Rapid Content sampler. Reflectance values obtained were relative to that from a nominally 80% reflective Coors standard ceramic disk. Relative reflectance values (R') were transformed by $\log(1/R')$.

Extraction and Chemical Assay for Lomefloxacin Hydrochloride Implants—After acquiring NIR spectra, each polymer slice was weighed and dissolved in methylene chloride (10 mL) in a 125 mL separatory flask. Hydrochloric acid (1 mM, 50 mL) was added to the separatory flask, forming two phases. The flask was shaken thoroughly, and the two phases were allowed to separate. Upon separation, the aqueous phase (top) was removed and placed into a 250 mL volumetric flask. This extraction procedure was repeated four times, and the resulting pooled extracts were diluted to volume with 1 mM HCL. An appropriate dilution was made and lomefloxacin quantified by measuring its absorbance at 287 nm using a Hewlett-Packard UV/Vis Spectrophotometer (Model 8450). An extraction efficiency of 99.6%, with a standard deviation of 0.85% ($n = 3$), was determined by separately adding known amounts of each component of the implant to a separatory flask and performing the extraction procedure.

NIR Spectral Analysis and Standard Curve Generation—A second derivative transformation of each NIR spectrum was performed using the NIRSystems Spectral Analysis Software (NSAS Version 3.50). The software was also utilized to scan the resulting second derivative spectra to determine a ratio of wavelengths which provided high correlation between the second derivative response and the theoretical PEG content or lomefloxacin content from extraction and UV analysis. A ratio of responses at two wavelengths was chosen rather than the response at a single wavelength to correct for baseline shifts. Baseline shifts are attributable to subtle changes in path length resulting from sample variations such as surface roughness, changes in sample positioning, or changes in sample density. The use of wavelength ratios has been shown to normalize spectra and yield more reproducible results.[19,20] A standard curve was generated by plotting the second derivative ratio versus PEG or lomefloxacin HCl content.

Partial least squares (PLS) analysis on second derivative spectra[21] was also performed for comparative purposes. Derivatized spectra have been shown to produce calibration models with more accurate and reproducible results.[22] A PLS calibration equation was generated using NSAS Version 3.50 and then utilized to predict lomefloxacin loadings in the validation data set.

Validation Set Generation—A separate batch of implants (20% w/w lomefloxacin HCl) was produced using the procedure described above in order to validate the standard curve generated. These implants were not used in the generation of the standard curve. Four implants from this batch were selected at random, and NIR spectra were obtained on two slices from each implant, as described previously. Lomefloxacin content was determined using the extraction and UV assay described above. The lomefloxacin content determined from the UV assay was then compared to the calculated lomefloxacin content using the NIR methods.

Statistical Analysis—A paired *t*-test was employed for comparison of lomefloxacin HCl content predicted by the NIR method and the results from extraction/UV assay. Using the paired *t*-test, 95% confidence intervals were constructed for the difference in the lomefloxacin hydrochloride content predicted by the NIR method and the results from the extraction/UV assay (i.e., NIR results − UV results). The null hypothesis (H_o) for this test was that of no significant difference while the alternative hypothesis (H_a) was that of significant difference. The results of a paired t-test give an indication of the accuracy of the NIR method compared with the extraction/UV assay. To perform a more robust statistical analysis on a small sample set, a nonparametric statistical analysis (Wilcoxon signed rank test at 95% confidence) was also employed.[23] The results of this statistical test provided a 95% confidence interval and a *p*-value which may be used in a manner similar to that obtained from the parametric paired *t*-test. An *F*-test for sample variance was employed at a 95% significance level to compare the precision of various NIR methods with the extraction/UV assay. In addition to the tests described above, standard error of calibration (SEC) and standard error of prediction (SEP) values were calculated for single wavelength and PLS models. Statistical analyses were performed on a microcomputer using MINITAB for Windows (Release 12.1), SAS, Version 6.12 (SAS Institute, Cary, NC), and Microsoft Excel 97.

Results and Discussion

NIR for Determination of PEG Content in PCL/PEG Implants—NIR spectra for PCL implants containing various PEG contents were obtained. To correct for the baseline shifts apparent in the samples and to amplify small spectral differences attributable to PEG content, a second derivative transformation of the NIR spectra was performed. Using the NSAS software, the spectra were analyzed to determine a wavelength ratio which best correlated with the known PEG content. A ratio of the responses at 2064 nm/1698 nm provided the highest correlation with PEG content. This region of the second derivative NIR spectrum is shown in Figure 1. The second derivative values at 2064 nm correspond well with changes in PEG content. A standard curve was constructed from the second derivative ratio of responses at 2064 nm/1698 nm versus the theoretical PEG content (% w/w) of each implant. The resulting standard curve is shown in Figure 2. The calibration data was analyzed by linear regression

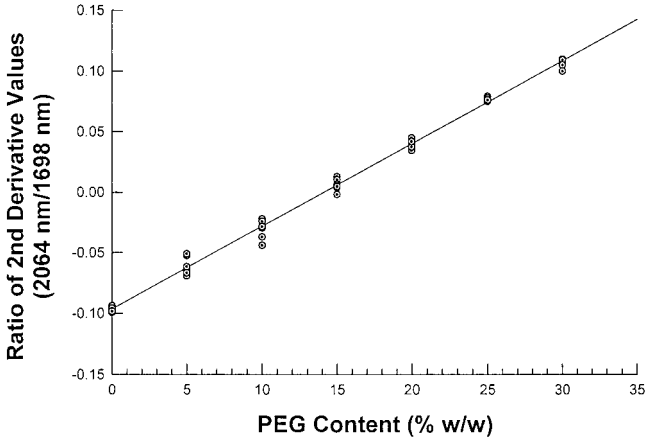

Figure 2—NIR standard curve for poly(ethylene glycol) (PEG) content in poly(ϵ-caprolactone) implants using a ratio of second derivative values (2064 nm/1698 nm) (R^2 = 0.998, S. E. = 0.0045).

Table 1—Comparison of NIR Predicted and Theoretical PEG 600 Content in Poly(ϵ-caprolactone) Implants

theoretical content (% w/w)	predicted content (% w/w) (n = 16)	standard deviation (% w/w) (n = 16)	relative error (%)
12.50	12.68	0.31	1.44
22.49	22.76	0.56	1.20

and excellent linearity throughout the entire range of PEG loadings (0−30% w/w) was obtained (R^2 = 0.998, SE = 0.0045).

Predicting PEG Content in PCL/PEG Implants from NIR Spectra—To test the robustness and accuracy of the NIR technique for the prediction of PEG content within a PCL implant, two batches of implants with theoretical PEG loadings of 12.5% and 22.5% w/w were prepared. NIR spectra were obtained and a second derivative transformation was performed. Using the second derivative of the response at 2064 and 1698 nm and the standard curve in Figure 2, PEG content was calculated and compared to theoretical PEG content. Table 1 shows the PEG content determined by the NIR method is in excellent agreement with the theoretical content. This method provides a rapid analytical technique for measuring PEG content with low relative error (1.2−1.4%) which is significant for two reasons. First, the technique is nondestructive, allowing subsequent use of the implant in other studies such as stability studies, in vitro/in vivo release studies, or polymer/excipient interaction studies, etc. Second, this technique provides an analytical method for quantitation of an excipient lacking a UV chromophore. Typical approaches to quantification of PEG or other excipients lacking a chromophore rely on methods such as refractive index detection with HPLC[24] or chemical reaction methods, which are more time-consuming and destroy the dosage form.

NIR for Determination of Lomefloxacin HCl Content in PCL/PEG Implants—NIR spectra for PCL/PEG implants containing various contents of lomefloxacin HCl are shown in Figure 3. A second derivative transformation of the NIR spectra of implants containing lomefloxacin was performed. The extraction procedure, previously described, was used to determine lomefloxacin content, and the results are summarized in Table 2. To determine a wavelength ratio which provided the best correlation between the second derivative NIR values and lomefloxacin content (Table 2), second derivative spectra were analyzed using the NSAS software. A ratio of the responses at 2172 nm/2226 nm provided the highest correlation with lomefloxacin content. This region of the second derivative NIR spectrum has been expanded in Figure 4A. A standard curve was constructed from the second derivative ratio of responses at 2172 nm/2226 nm versus lomefloxacin content determined from the extraction/UV assay results. The resulting standard curve, shown in Figure 4B, demonstrates excellent linearity (R^2 = 0.992, S. E. = 0.036).

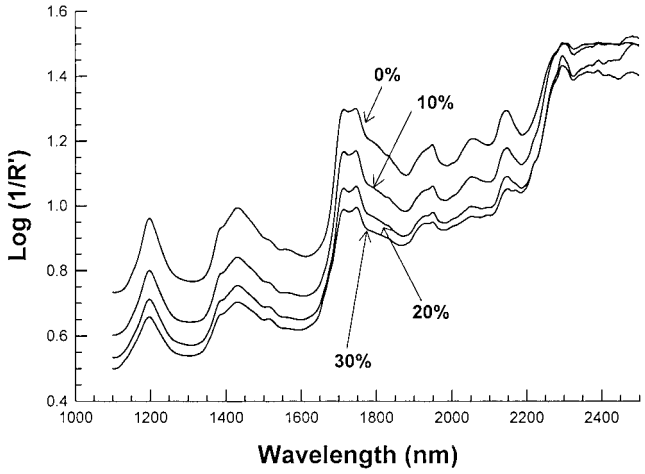

Figure 3—NIR spectra for poly(ϵ-caprolactone) implants containing various lomefloxacin HCl contents (% w/w) as indicated on each spectrum.

Table 2—Lomefloxacin HCl Content of Calibration Samples As Determined by the Extraction Procedure with UV Analysis

implant no.	lomefloxacin HCl content (% w/w)	implant no.	lomefloxacin HCl content (% w/w)
5-1	5.75	15-3	15.04
5-2	5.55	15-4	15.08
5-3	4.62	20-1	19.13
5-4	4.84	20-2	18.92
10-1	10.05	20-3	17.75
10-2	10.25	25-1	25.11
10-3	9.82	25-2	23.83
10-4	9.87	25-3	24.82
15-1	14.80	25-4	24.66
15-2	14.70		

In addition to using single wavelength analysis, partial least squares analysis was performed on second derivative spectra for comparison. A three-factor calibration equation was developed with an R^2 of 0.998 and a standard error of 0.66.

Predicting Lomefloxacin HCl Loading in PCL/PEG Implants—Implants containing approximately 20% w/w lomefloxacin HCl were produced to test the predictive ability of the NIR method. NIR spectra and second derivative spectra were obtained on 5 mm slices of four implants, as described previously, and subjected to extraction and subsequent UV assay. The second derivative response at 2172 nm/2226 nm was then used with the standard curve (Figure 4B) to predict lomefloxacin HCl content. The three-factor PLS calibration equation was also used to determine lomefloxacin content using the "Predict Percent" feature of the NSAS software. Lomefloxacin contents determined from both NIR methods and the extraction/UV method are shown in Table 3. These results were statistically analyzed for significant differences in the accuracy and precision of the two methods. Results of the statistical analysis are summarized in Table 4. The paired t-test and Wilcoxon signed rank test gave 95% confidence intervals containing zero and p-values greater than 0.05, indicating that results for lomefloxacin content predicted by NIR were not statisti-

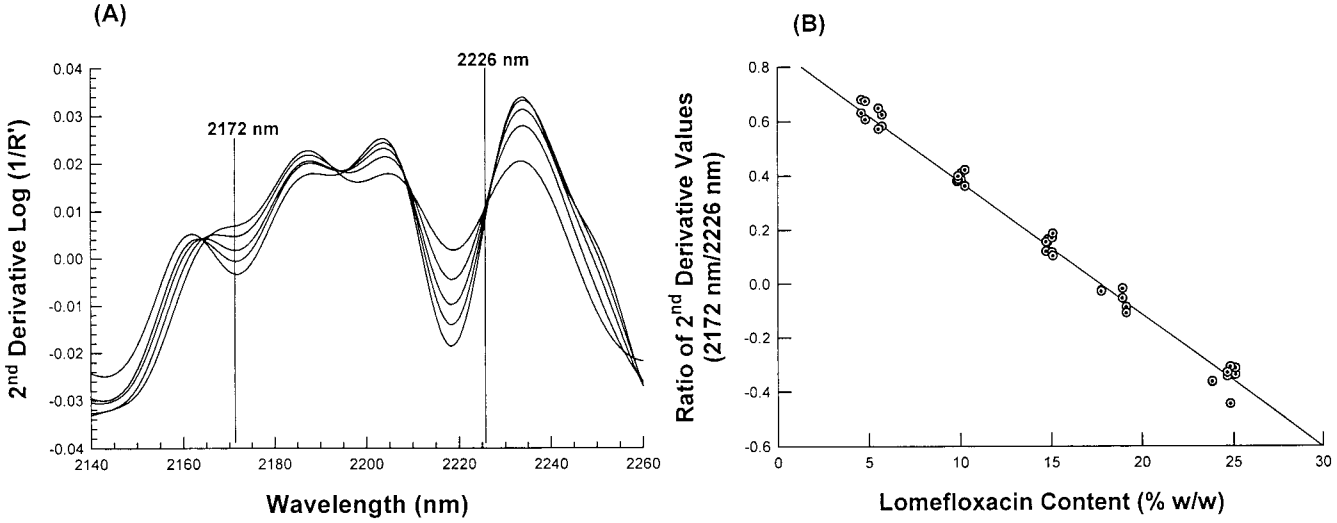

Figure 4—(A) Expanded second derivative NIR spectra for PCL:PEG implants containing lomefloxacin HCl. Content from top to bottom at 2172 nm: 25, 20, 15, 10, and 5% w/w; the normalizing wavelength (2226 nm) is indicated. (B) NIR standard curve for lomefloxacin HCl content in PCL:PEG implants using a ratio of second derivative values (2172 nm/2226 nm) (R^2 = 0.992, S. E. = 0.0364).

Table 3—Lomefloxacin Content of Validation Samples as Determined by Extraction/UV Procedure and NIR Methods

	extraction/UV procedure (% w/w)	NIR 2172 nm/ 2226 nm (% w/w)	NIR 1824 nm/ 1862 nm (% w/w)	NIR PLS analysis 3 factors (% w/w)
	18.84	18.33	19.11	19.91
	18.98	18.73	19.95	20.33
	18.57	18.49	17.52	18.84
	18.61	18.03	17.14	19.11
	18.93	18.59	21.89	18.85
	19.01	20.29	16.40	19.15
	19.36	21.59	19.54	19.58
	19.26	19.88	20.28	19.01
average	18.95	19.24	18.98	19.35
std dev	0.28	1.23	1.84	0.54
% RSD	1.48	6.38	9.69	2.79

Table 4—Statistical Analysis of NIR and Extraction/UV Techniques for Determination of Lomefloxacin Content within PCL Implants

statistical test	2172 nm/ 2226 nm versus extraction/UV	1824 nm/ 1862 nm versus extraction/UV	PLS (three factors) versus extraction/UV
SEC	0.77	1.76	0.66
SEP	1.05	1.73	0.70
paired *t*-test			
•95% interval	(–0.545, 1.137)	(–1.412, 1.480)	(–0.059, 0.864)
•*p*-value	$p > 0.05$	$p > 0.05$	$p > 0.05$
Wilcoxon signed rank test			
•95% interval	(–0.42, 1.07)	(–1.26, 1.57)	(–0.015, 0.810)
•*p*-value	$p > 0.05$	$p > 0.05$	$p > 0.05$
F-test	$p < 0.05$	$p < 0.05$	$p > 0.05$

cally different than results from UV analysis in terms of accuracy. SEC and SEP values (Table 4) for each calibration model were similar to one another and low in value (i.e. < 2%), further validating the calibration models. The NIR calibration models may be compared by means of the *F*-test shown in Table 4. While both single wavelength and PLS methods give results comparable in accuracy to the extraction/UV method, the PLS method yields more precise results (*p*-value > 0.05) than the single wavelength method. The smaller SEC and SEP values for the PLS model further verify this result. This finding suggests that PLS models may be more useful when accurate and precise mean content is required.

NIR Spectral Interpretation—The results above demonstrate the utility of NIR spectroscopy for determination of lomefloxacin HCl within polymer implants. To structurally interpret NIR results, it is advantageous to utilize a portion of the NIR spectrum unique to the compound of interest and that is predictable from mid-infrared data. With this approach, a nondestructive analytical technique directly related to structural features of the analyte could be developed. Interpretation is often accomplished with the use of wavelength tables which relate common functionalities to corresponding NIR absorption bands.[20,25–28] One disadvantage of using these tables is that absorption bands for a given functionality are often broad, resulting in several functionalities which may be expected to have overtone transitions within the same region. This ambiguity may be alleviated through the use of the corresponding mid-infrared data. NIR absorption bands are the result of overtones or combinations of overtones originating in the fundamental midrange (4000−600 cm^{-1}) infrared region of the spectrum.[29] When frequencies of fundamental transitions in the mid-infrared region of the spectrum are known, the position of expected near-infrared absorption bands may be calculated. The overtone transitions (λ) will occur at integer multiples (n) of fundamental vibrational frequencies (ν_{IR}), which may be estimated from known mid-infrared absorption bands using:

$$\lambda = \frac{10\,000\,000}{n\nu_{IR}(cm^{-1})} \quad (1)$$

Sanzgiri et al. obtained the mid-infrared spectrum for lomefloxacin HCl and assigned mid-infrared absorption bands to various functionalities (Table 5).[30] Overtone transitions from the mid-infrared absorption bands were calculated using eq 1.

As shown previously, the NIR response at a wavelength ratio of 2172 nm/2226 nm correlated well with lomefloxacin content, and these results were comparable to UV analysis. These wavelengths do not correspond to the predicted overtone transitions of the assigned bands (Table 5). Because the use of infrared data did not provide a useful interpretation of the 2172 nm region, various NIR tables

Table 5—Mid-Infrared Transitions and Calculated Overtone Transitions for Lomefloxacin HCl[a]

infrared fundamental[a]	assignment	theoretical 1st overtone (nm)	theoretical 2nd overtone (nm)
3703 nm (2700 cm^{-1})	NH_2^+ stretch	1852	1235
6172 nm (1620 cm^{-1})	carbonyl stretch (pyridinone ring)	3086	2058
8278 nm (1208 cm^{-1})	aryl fluorides	4139	2759

[a] Mid-infrared absorption peaks and assignments are from Sanzgiri et al.[30]

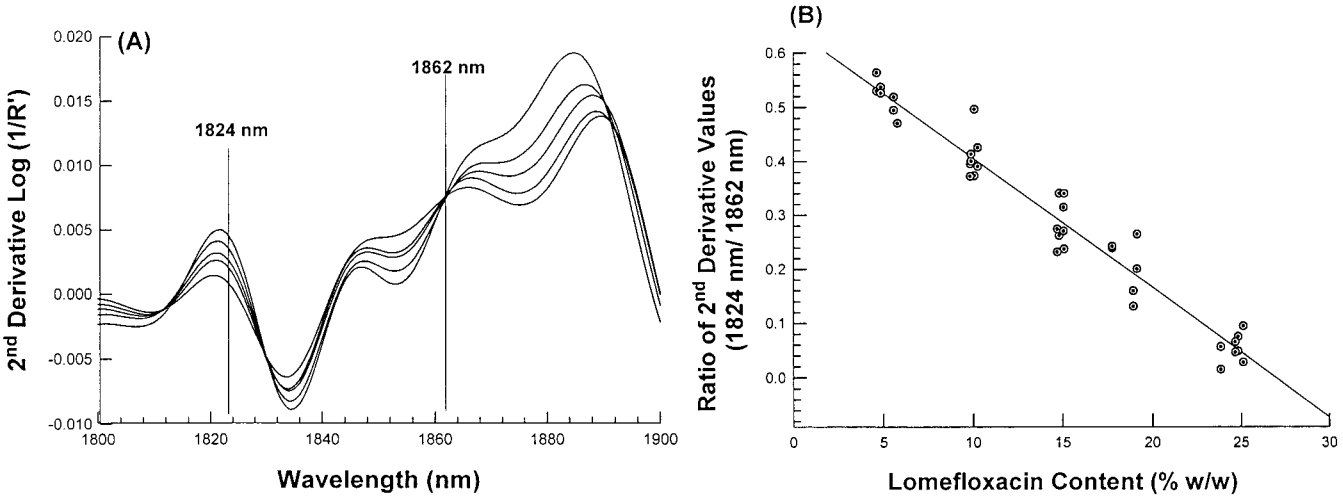

Figure 5—(A) Expanded second derivative NIR spectra for PCL:PEG implants containinglomefloxacin HCl contents. Content from top to bottom at 1824 nm: 25, 20, 15, 10, and 5% w/w; the normalizing wavelength (1862 nm) is indicated. (B) NIR standard curve for lomefloxacin HCl content in PCL:PEG implants using a ratio of second derivative values (1824 nm/1862 nm) (R^2 = 0.955, S. E. = 0.0364).

were utilized to provide an interpretation of why this provided good correlation. Amines are reported to have an combination N−H stretch in the region of 2100−2200 nm.[14] Lomefloxacin HCl is the only amine-containing species within these implants, and thus we may interpret our correlation at 2172 nm as being due to N−H combination frequencies within the NIR. It should be noted that increasing relative reflectance values within the NIR spectra will lead to decreasing second derivative values. The 2172 nm wavelength could not be predicted from mid-IR data since the mid-IR data will only provide information about overtone transitions occurring from specific functional groups, not from combination frequencies.

Since a reasonable correlation attributable to an amine combination was found at 2172 nm, we may also expect to find good correlation in the region where a first overtone may be expected from the mid-IR data. From Table 5, a protonated amine vibrational stretch would be expected to have a theoretical first overtone transition at 1852 nm. The second derivative spectra of lomefloxacin-containing implants were investigated for correlation with lomefloxacin content in the range of 1800 to 1900 nm corresponding with the theoretical first overtone transition as predicted from the known IR spectrum. Another wavelength ratio (1824 nm/1862 nm) also provided good correlation with lomefloxacin content. This region of the NIR spectra has been expanded and is shown in Figure 5A. A standard curve was constructed from the second derivative ratio of responses at 1824 nm/1862 nm versus lomefloxacin content determined from the extraction/UV assay results. The resulting standard curve (R^2 = 0.955, S. E. = 0.036) is given in Figure 5B. The increased scatter in the data may be attributable to the weaker absorbance found in the 1800−1900 nm range. Various other transitions such as carbon−hydrogen first overtone transitions also occur in this region and may also contribute to the increase in scatter of the data at 1824 nm.[14] To test the predictive ability of the NIR at this new wavelength ratio, second derivative responses at 1824 and 1862 nm were obtained from the test set of implants and used with the standard curve in Figure 5B to predict lomefloxacin content as shown in Table 3. A statistical analysis was performed to compare these results with previous NIR and extraction/UV results. Results from this statistical analysis are shown in Table 4. As can be seen from Table 4, the paired *t*-test and Wilcoxon signed rank test give 95% confidence intervals containing zero and *p*-values greater than 0.05. Furthermore, the SEC and SEP values for the NIR calibration at this new wavelength are similar to one another and small in value. These results indicate that there is no statistical difference in the accuracy of mean lomefloxacin content predicted by NIR (1824 nm/1862 nm) or UV analysis. The significance of this is that the wavelengths correlated well with first overtone expectations for a protonated amine as calculated from mid-infrared data. This ratio also provided reasonable correlation with results from extraction/UV analysis. The high correlation in the 1800−1900 nm region where an expected N−H first overtone transition would occur supports the proposed N−H combination interpretation for the 2172 nm/2226 nm ratio. These results demonstrate that mid-infrared data may be useful in structural interpretation of NIR spectra and can help to verify interpretation of NIR combination transitions not predictable from mid-IR spectra alone.

Although the 1824 nm/1862 nm wavelength ratio provides results with comparable accuracy as the extraction/UV technique, the *F*-test demonstrates the single wavelength NIR method (1824 nm/1862 nm) does not give results with the same precision (i.e. p-value < 0.05). The PLS method appears to be the most robust method in terms of accuracy and precision; however, it should be noted that the PLS method does not allow for a similar direct interpretation of the NIR data.

Conclusions

NIR spectroscopy is an accurate and nondestructive method for quantifying components within polymeric implants and provides a useful alternative to traditional destructive techniques. This nondestructive technique may be particularly useful in the early stages of product development when drug supply is limited or when dose uniformity is an issue within test formulations. In the case of polymer matrix systems, excipients such as poly(ethylene glycol) are not normally assayed. Given the importance these excipients have in controlling the release rate of active components, it is critical to assess both the quantity and uniformity of these excipients within the polymeric dosage form. NIR seems to provide an excellent and rapid nondestructive method for quantitation of poly(ethylene glycol), an excipient which is tedious and time-consuming to quantify by other analytical methods.[24] Preliminary work suggests that similar results may be obtained for quantifying actives within other polymeric dosage forms such as microspheres or films.[31] Selection of analytical wavelengths in the near-infrared region corresponding to structural features of the analyte may be accomplished with the use of corresponding mid-infrared spectral data and NIR frequency (wavelength) tables.

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