Effect of surfactants or a water soluble polymer on the crystal transition of clarithromycin during a wet granulation process

Kenji Nozawa[a,b], Yasunori Iwao[a], Shuji Noguchi[a] and Shigeru Itai[a],*

KEY WORDS: clarithromycin; crystal transition; wet granulation; surfactant; water-soluble polymer.

[a]*Department of Pharmaceutical Engineering, School of Pharmaceutical Sciences, University of Shizuoka, 52-1 Yada, Suruga-ku, Shizuoka 422-8526, Japan*

[b]*Pharmaceutical Development Department, Sawai Pharmaceutical Co., Ltd, 2-30, Miyahara 5-chome, Yodogawa-ku, Osaka 532-0003, Japan*

* Corresponding author: **Shigeru Itai, Ph.D.**, Professor

Department of Pharmaceutical Engineering, School of Pharmaceutical Sciences, University of Shizuoka, 52-1 Yada, Suruga-ku, Shizuoka 422-8526, Japan.

Tel.: +81 54 264 5614, Fax: +81 54 264 5615,

E-mail: s-itai@u-shizuoka-ken.ac.jp.

ABSTRACT

To generate products containing a stable form of clarithromycin (CAM) (form II) regardless of the initial crystal form of CAM or type of granulation solvent, the effects of five surfactants, or a water-soluble polymer (macrogol 400) were determined on the crystal transition of CAM. The metastable form (form I) was kneaded with water, after adding surfactants, or a water-soluble polymer. Form II was also kneaded with ethanol, after adding the same additives. The resulting samples were analyzed by powder X-ray diffraction. Form I was completely converted to form II by a wet granulation using water with additives bearing polyoxyethylene chains such as polysorbate 80 (PS80), polyoxyl 40 stearate or macrogol 400. The granulation of the form II using ethanol with these additives did not result in a crystal transition to form I. Furthermore, CAM tablets were manufactured using granules with PS80, and these crystal forms and dissolution behaviors were investigated. As a result, the wet granulation of CAM with PS80 gave CAM tablets containing only form II and PS80 did not have any adverse effects on tablet characteristics. Therefore, these data suggests that the crystal form of CAM can be controlled to be form II using a wet granulation process with additives bearing polyoxyethylene chains regardless of the initial crystal form of CAM or type of granulation solvent.

ABBREVIATIONS: CAM, clarithromycin; SDS, sodium lauryl sulfate; LCT, soybean lecithin; SFE, sucrose fatty acid ester; PS80, polysorbate 80; POS40, polyoxyl 40 stearate; PEG400, macrogol 400; PXRD, powder X-ray diffraction; L-HPC, low-substituted hydroxypropylcellulose.

INTRODUCTION

Clarithromycin (CAM), which is a 14-membered semi-synthetic macrolide antibiotic, is more stable to acidic conditions than erythromycin (Nakagawa et al, 1992) and exhibits a broad range of antimicrobial activities. CAM is widely used for the treatment of a variety of different infections, including *Helicobacter pylori* infection. Several tablet-based and pediatric formulations (i.e., granules for oral suspension) containing CAM have been developed and marketed throughout the world (Yajima et al, 1999; Yajima et al, 2002). The total annual sales of generic CAM products in Japan equates to more than 340 million dollar (35 billion yen). It is noteworthy that it has been more than 20 years since branded CAM products were available to buy in Japan.

Nine crystal forms of CAM have been reported in the literature, including form 0 (ethanol solvate) (Spanton et al, 1999), form I (metastable form) (Liu et al, 1999; Noguchi et al, 2012; Tozuka et al, 2002), form II (stable form) (Tozuka et al, 2002; Liu et al, 1998; Suh et al, 2002; Sohn et al, 2000; Tian J et al, 2011), form III (acetonitrile solvate) (Liu et al, 2003), form IV (hydrate) (Avrutov et al, 2003; Jacco, 2012), form V (Gruss et al, 2008), a hydrochloride salt (Parvez et al, 2000; Noguchi et al, 2014) and a methanol solvate (Iwasaki et al, 1993). Polymorphic crystals generally exhibit significant differences in their individual physicochemical properties, including their solubility, stability and bioavailability properties. These differences can have a significant impact on the therapeutic properties of medicinal agents, and the selection of

the optimal crystal form of a medicinal agent is therefore one of the most important factors governing the development of pharmaceutical formulations. The CAM products currently marketed in Japan are formulated using the most thermodynamically stable from of the CAM crystals, which is form II (Liu et al, 1998; Suh et al, 2002; Tian J et al, 2011). The purification of form II is typically achieved by the conversion of crystal form 0 or I to form II using temperatures greater than 80 °C under vacuum conditions (Liu et al, 1999; Liu et al, 1998; Suh et al, 2002; Sohn et al, 2000; Tian J et al, 2011). The development of a novel process for the preparation of form II that avoids the use of high temperature conditions could therefore reduce the costs associated with the manufacture of these products, as well as production cost of the active pharmaceutical ingredient.

Concerns remain that form II of CAM could undergo a crystal transition during the manufacturing process to give the metastable form of CAM. Although various pharmaceutical techniques have been used to produce solid dosage forms such as wet granulation, dry granulation and direct tableting, wet granulation may be the most appropriate technique for the CAM formulation process, because this technique can improve the surface condition of CAM with a highly adhesive property. During the wet granulation process, an organic solvent can also be used in addition to water for the formulation of CAM to induce the uniform granulation of CAM powders with a

water-insoluble property. However, when the wet granulation of form II CAM powders is performed in the presence of an organic solvent, such as ethanol, the CAM crystals can be converted from form II to form I via form 0 (Spanton et al, 1999). It is therefore critically important to suppress the crystal transition of CAM from form II to any of its other forms and to promote the crystal transition to form II during the wet granulation of CAM in the presence of an organic solvent.

To overcome the problems listed above, we focused on the use of surfactants, because several surfactants have been reported to induce the solution-mediated crystal transition of drug compounds (Roderiguez-Hornedo and Murphy, 2004). In this study, we have established a simple technique to enhance the crystal transition of CAM from form I to form II, whilst preventing the crystal transition of the form II crystals during the pharmaceutical manufacturing process by means of additives bearing polyoxyethylene chains.

MATERIALS AND METHODS

Materials

Forms I and II of CAM were obtained from Kyonbo pharmaceutical Co., Ltd (Chungchongnam, Korea) and Ercros Industrial S.A. (Barcelona, Spain), respectively. Sodium lauryl sulfate (SDS), which is an anionic surfactant, was obtained from Sigma Aldrich (Tokyo, Japan). Soybean lecithin (LCT), which is an amphoteric surfactant, was

obtained from Nacalai Tesque (Tokyo, Japan). Sucrose fatty acid ester (SFE), polysorbate 80 (PS 80) and polyoxyl 40 (POS40) stearate, which are non-ionic surfactants, were obtained from Mitsubishi-Kagaku Foods Co. (Tokyo, Japan), Kanto Chemical (Tokyo, Japan) and NOF Co. (Tokyo, Japan), respectively. Macrogol 400 (PEG400), which is a water-soluble polymer, was obtained from NOF Co. Corn starch, which is used as a filler, was obtained from Nihon Shokuhin Kako Co., Ltd. (Tokyo, Japan). Low-substituted hydroxypropyl cellulose (L-HPC; used as a disintegrant) was obtained from Shin-Etsu Chemical Co., Ltd. (Tokyo, Japan). Light anhydrous silicic acid (used as a plasticizer) was supplied by Freund Co., Ltd (Tokyo, Japan). Magnesium stearate (used as a lubricant) was purchased from Taihei Chemical Industrial Co., Ltd (Tokyo, Japan). Ethanol (>95%) was obtained from the Japan Synthetic Alcohol Co., Ltd (Kanagawa, Japan). All of the other reagents used in the current study conformed to the standards defined in the 16th Edition of the Japanese Pharmacopoeia (JP16).

Methods

Preparation of wet granules using form I and purified water

Five gram samples of form I were mixed with 0, 0.05, 0.25, 0.5 or 1.0 g of each surfactant or PEG400. The resulting mixtures were then treated with 0.75, 1.5 or 3.0 mL of purified water, before being kneaded for 2 min using a mortar and a pestle at room temperature. The wet granulated powders were subsequently sieved through a 2360-μm

screen, and the resulting granules were dried in an oven at 50 °C for 40 min. The dried granules were then sieved through a 1000-μm screen, and the resulting sieved powders were subjected to powder X-ray diffraction (PXRD) analysis.

Preparation of wet granules using form II and ethanol

Five gram samples of form II were mixed with 0 or 0.25 g of each surfactant or PEG400. The resulting mixtures were then treated with 0.75, 1.5 or 3.0 g of ethanol before being kneaded for 2 min at room temperature using a mortar and a pestle to give the corresponding granulated powders, which were sieved and dried according to the procedure described above for the "preparation of wet granulation powders of form I with purified water".

Preparation of wet granules using form II and purified water or using form I and ethanol

Five gram samples of form II or form I were mixed with 0 or 0.25 g of each surfactant or PEG400. The resulting mixtures containing form II were then treated with 1.5 g of water, and these containing form I were then treated with 1.5 g of ethanol before being kneaded for 2 min at room temperature using a mortar and a pestle. Granulation powders thus prepared were sieved and dried according to the procedure described above for the "preparation of wet granulation powders of form I with purified

147 water".

148

149 **PXRD**

150 The crystal forms of the CAM found in the granulation powders and tablets were
151 analyzed using a Bruker PXRD system (Bruker AXS Co., Ltd., Kanagawa, Japan). The
152 granulation powders and tablets were gently ground into fine powders using a mortar
153 and pestle before being packed into sample cups. The packed sample cups were then
154 subjected to PXRD analysis using CuK_α radiation (λ = 1.5418 Å), with the tube voltage
155 and amperage set to 40 kV and 40 mV, respectively. Scanning was conducted at room
156 temperature between 2θ angles of 2° and 40° with a scanning step width of 0.015° and a
157 scanning speed of 0.1 s/step.

158

159 **Difference scanning calorimetry (DSC)**

160 The crystal forms of the CAM in the granulation powders were analyzed using
161 DSC equipment (DSC-50, Shimadzu Corp, Kyoto, Japan). All the measurements were
162 performed using an empty aluminum pan as a reference under a nitrogen gas
163 atmosphere. The weighed solid samples (10.0 ± 1.0 mg) were put into the aluminum
164 pan and heated at a rate of 10°C/min. Forms I and II of CAM were analyzed at the range
165 of 40 to 250 °C whilst the granulation powders at the range of 40 to 180°C.

166

Preparation of the CAM tablets

The compositions of the tablets are summarized in **Table 1**. Form I or II of CAM, corn starch, L-HPC and light anhydrous silicic acid were weighed at 250 tablets per batch, according to **Table 1**. A ground sample of form I CAM was obtained by grinding the material in a hammer mill (PULVERISETTE 14, Fritsch Japan Co., Ltd., Yokohama, Japan). The particle sizes of the intact and the hammer milled CAM samples are shown in **Table 2**. The weighed powders were mixed for 1 min using a mortar and a pestle. The resulting mixture was then treated with a granulation solvent (water or ethanol) either with or without PS80 before being kneaded with a mortar and pestle. After the wet granulation process, the powders were sieved through a 2360-μm screen. The sieved powders were then kneaded with water and ethanol, which were used as granulation solvents, before being dried for 1–2 h in an oven at 70 and 50 °C, respectively. The dried granules were sieved through a 1000-μm screen, and the resulting sieved powders were placed into a plastic bag together with light anhydrous silicic acid and magnesium stearate, where they were mixed by shaking (60 times). The granules were compressed into tablets using a manual tableting hydraulic press (Kikusui Seisakusho Ltd., Kyoto, Japan) with a two-stage R-plane punch of 10 mm in diameter. The granules were compressed with a compression force of 6.0 kN. The weight of the resulting tablets was 320 mg, with each tablet containing 200 mg of CAM.

Measurement of the thickness and hardness properties of the CAM tablets

The thickness and hardness properties of the CAM tablets manufactured in the current study were measured using a dial gauge (Ozaki MFG. Co., Ltd., Tokyo, Japan) and hardness measuring apparatus (Freund Co., Ltd., Tokyo, Japan), respectively.

Disintegration Test

Disintegration tests were performed according to the procedure described in JP16 using a disintegration apparatus (Miyamoto Riken Ind. Co., Ltd., Osaka, Japan). Purified water was used as the test medium at 37.0 ± 0.5 °C.

Dissolution Test

The dissolution test was carried out according to the paddle method described in JP 16 using a dissolution apparatus (NTR-6100A, Toyama Sangyo Co., Ltd., Tokyo, Japan). Hydrochloric acid (pH 1.2) and phosphate buffer saline (pH 6.8) solutions were used as the dissolution media in accordance with the procedure described in JP16. The paddle rotation speed and temperature were set at 50 rpm and 37.0 ± 0.5 °C in 900 mL of the dissolution media, respectively. Twenty milliliter aliquots of the sample solution were withdrawn at predetermined time intervals and replaced with an equal volume of the dissolution medium. Each sample solution was filtered through a 0.45-μm membrane filter and diluted by 3-fold using a 0.2 mol/L potassium dihydrogen phosphate solution.

208 The amount of CAM in the dissolution media was determined by
209 high-performance liquid chromatography (HPLC) (Shimadzu Corp., Kyoto, Japan)
210 using an Inertsil ODS-2 column (4.6 × 150 mm; GL Science Inc., Tokyo, Japan), which
211 was kept at 50 °C in a column oven. The wavelength of the UV detector was set to 210
212 nm. The column was eluted with a mobile phase consisting of a mixture of 1/15 M
213 potassium dihydrogen phosphate and acetonitrile (13:7, *v*/*v*) at a flow rate of 1.3
214 mL/min. The injection volume was set at 100 μL. For the quantification of CAM at pH
215 1.2, the sum of the peaks corresponding to CAM and its degradation product (Morimoto
216 et al, 1990) were regarded as the total amount of CAM. The dissolution amount of
217 CAM in solution at pH 6.8 was calculated from the area of the peak corresponding to
218 CAM.

219

220 **Statistic**

221 The differences in the hardness and disintegration time properties between the
222 tablets made from F1 and those that were made from the other formulations evaluated in
223 the current study were statistically analyzed using an F-test and a Student t-test or the
224 Welch t-test. Differences with $p < 0.01$ were considered to be statistically significant.

225

RESULTS AND DISCUSSION

Effect of surfactants or PEG400 on crystal transition of CAM by wet granulation with purified water

The PXRD patterns of forms I and II, as well as the granulation powders derived from form I using only water, are shown in **Fig. 1**. The specific diffraction peaks of forms I and II were observed at 2θ = 5.0°, 6.5°, 7.9° and 10.2°, and 2θ = 8.5°, 9.4°, 10.8° and 11.4°, respectively. When form I was granulated with water containing no surfactants, PXRD analysis revealed the appearance of the specific diffraction peaks of form II, as well as those belonging to form I (**Fig. 1**), which indicated that the wet granulation of form I with water did not lead to its complete transformation to form II.

Several additives were also investigated in terms of their ability to induce the crystal transition of CAM. The PXRD patterns of samples obtained by the wet granulation of form I with water in the presence of surfactants or PEG400 are shown in **Figs. 2 and 3**. The specific diffraction peaks of SDS and SFE were observed at 2θ = 2.5° and 4.5°, and 2.5°, respectively. During the wet granulation with SDS, the wettability of the form I CAM powders improved considerably compared with the corresponding granulation process without the surfactant. In the kneaded CAM samples containing SDS concentrations in the range of 5 to 10 wt%, the material existed in the capillary state. However, the capillary state changed into a slurry state as the amount of SDS was increased to 20 wt%. Although the properties of the kneaded samples changed

246 depending on the amount of SDS that had been added to the mixture, form I was not
247 completely transformed to form II under any of these conditions (**Fig. 2a**). Incomplete
248 transitions from form I to form II were also observed when the wet granulation process
249 was performed with water in the presence of LCT or SFE (**Fig. 2b and 2c**). In addition,
250 the specific diffraction peaks at 2θ = 6°, 8° and 10.5° were considered to be derived
251 from unknown crystal forms of CAM.

252 The wet granulation of form I with water in the presence of PS80 led to an
253 improvement in the dispersion state of the form I particles, which improved further as
254 the amount of PS80 added to the mixture was increased. Furthermore, the PXRD
255 patterns of the wet granulation powders prepared with PS80 showed that the specific
256 diffraction peaks belonging to form I of CAM completely disappeared following the
257 addition of more than 5wt% PS80 (**Fig. 3a**). This result therefore indicated that form I
258 was completely transformed to form II under these conditions. A complete transitions
259 from form I to form II was also observed when the wet granulation process was
260 performed with more than 5wt% POS40 or PEG400 (**Fig. 3b and 3c**). DSC analysis
261 was also performed using form I crystals which had been kneaded with 30wt% water
262 and 5wt% additives (**Fig. 4**). DSC curve of the intact form I crystals showed an
263 exothermic peak derived from crystal transition to form II at around 125°C, and an
264 endothermic peak derived from crystal melting at 228°C, while that of the intact form II

showed only an endothermic peak at 228°C. DSC curves of the form I powders kneaded with PS80, POS40 or PEG400 did not show the exothermic peak, indicating that form I had been transformed to form II by just kneading with PS80, POS40 or PEG400. Taken together, these results indicate that the degree of crystal transition from form I to form II is dependent on the types of surfactant and water soluble polymer added to the wet granulation process.

The amount of water added to the granulation of CAM is one of the most important factors governing the extent of the crystal transition from form I to form II, and several previously published reports have demonstrated that form II can be obtained by heating an aqueous slurry of either form 0 or I at 70–80 °C (Liu et al, 1998; Suh et al, 2002; Tian J et al, 2011). The results of the current study demonstrated that a portion of form I could be transformed to form II following a wet granulation process using 30 wt% water (**Fig. 1**), which suggested that the crystal transition of CAM from form I to form II could potentially be controlled by varying the amount of water added to the wet granulation process. With this in mind, we investigated the influence of the amount of water added to the wet granulation process on the crystal transition of form I. Form I crystals of CAM were treated with different amounts of water (i.e., 15, 30 and 60 wt%) to give pendular, funicular or capillary and slurry states of form I, respectively. The ratios of surfactants and PEG400 to form I were fixed to 5 wt%, which was determined

to be the minimal amount needed for complete crystal transition from form I to form II, as mentioned above (**Fig. 3**). The PXRD patterns of the various samples obtained in the experiments are shown in **Figs. 5 and 6**. Wet granulation processes with water and water in the presence of SDS resulted in a decrease in the intensities of the specific diffraction peaks belonging to form I, while the intensities of the specific diffraction peaks belonging to form II increased in proportion to the amount of water added to the process (**Fig. 5a and 5b**). Furthermore, when form I was kneaded with 60 wt% water, the kneaded state of form I changed from a pendular state to a slurry state, and form I was completely converted to form II. Although there was an increase in the intensities of the specific diffraction peaks belonging to form II when form I was kneaded with 60 wt% water in the presence of LCT, a complete transition from form I to form II was not observed. Specific diffraction peaks belonging of form II were barely observed by PXRD when SFE was added to the granulation process, even when the amount of water was increased from 5 to 60 wt% (**Fig. 5d**). These results suggested that the addition of SFE did not induce the transition of the CAM crystals from form I to form II. However, the kneading state of the form I crystals mixed with 15 wt% water containing PS80, POS40 or PEG400 was found to be pendular, which was the same as that found following the addition of LCT or SFE. In all of these cases, the intensities of the specific diffraction peaks belonging to form I decreased, whereas those belonging to form II

303 increased (**Fig. 6**). When 30 or 60 wt% water was added during the kneading of form I
304 with PS80, POS40 or PEG400, the PXRD patterns of the resulting powders were
305 identical to that of form II (**Fig. 6**), which indicated that form I was completely
306 converted to form II when the amount of water in the granulation process was over 30
307 wt%. In addition, when the wet granulation of form II was conducted with water and
308 additives, it was confirmed that any crystal transition did not occur (**Fig. 7**).

309 The results obtained thus far can be summarized as follows. When the wet
310 granulation of form I was carried out using only water or water containing SDS, the
311 transformation of the form I crystals to form II crystals was incomplete when less than
312 30 wt% water was added to the granulation process. With regard to LCT or SFE, the
313 extent of the transformation of the crystals from form I to form II was lower than that
314 observed for the wet granulation in the absence of these agents, even when the kneaded
315 material reached to slurry state. In contrast, the addition of PS80, POS40 or PEG400 to
316 the wet granulation process led to the complete transformation of the crystals from form
317 I to form II when 30 wt% of water was added as a solvent. These results suggested that
318 a robust granulation process for the complete transformation of the CAM crystal from
319 form I to form II was developed, and this new process was less dependent on the
320 amount of water added to the granulation by using PS80, POS40 or PEG400.

321

Effect of a surfactant or PEG400 on the crystal transition of CAM by wet granulation with ethanol

It was envisaged that the wet granulation of form II in ethanol would induce to the transformation of the CAM crystals from form II to form I. Given that PS80, POS40 and PEG400 promoted the conversion of the CAM crystals from form I to form II, it was expected that the addition of these additives to a wet granulation process involving form II would suppress the conversion of the crystals to form I, even when ethanol was used as a solvent. The PXRD patterns of samples obtained following a wet granulation process using ethanol with form II in the presence or absence of surfactants and PEG400 are shown in **Fig. 8**. When the granulation process was without any additives, PXRD analysis of the resulting powders revealed specific diffraction peaks belonging to form 0 (i.e., 2θ = 4.7° and 6.6°) and form I (i.e., 2θ = 7.9° and 10.2°), as well as those belonging to form II, which indicated that form II was being converted to forms 0 and I when it was subjected to a wet granulation process using ethanol. The conversion of from II crystals to crystals of forms 0 and I was also observed when the wet granulation process was conducted with SDS, LCT or SFE. In contrast, in the addition of PS80, POS40 or PEG400 to the wet granulation of form II CAM crystals appeared to stabilize the crystals and the PXRD patterns of these samples were almost identical to that of the form II material. Taken together, these results show that the addition of PS80, POS40 or

PEG400 to the wet granulation of CAM with ethanol might prevent the conversion of the form II crystals to forms 0 and subsequent forms I, or promote the conversion from once transited forms 0 and subsequent I to form II.

The influence of the amount of ethanol added to the wet granulation process was also investigated in terms of its impact on the crystal transition of form II. The ratio of ethanol to the form II crystals was varied (i.e., 15, 30 and 60 wt%), whilst the ratio of surfactant or PEG400 to the form II crystals was fixed at 5 wt%. The PXRD patterns of these samples are shown in **Figs. 9 and 10**. When the wet granulation of form II was carried out using only ethanol, a portion of form II was transformed to form 0 and I following the addition of more than 30 wt% ethanol (**Fig. 9a**). The result of the PXRD analysis revealed that the intensities of the specific diffraction peaks belonging to forms 0 and I increased as the amount of ethanol increased during the wet granulation of the from II crystals in the presence of SDS, LCT or SFE (**Figs. 9b–d**). In contrast, the PXRD patterns of the form II powders granulated with PS80 were identical to that of form II, even when the amount of ethanol was increased from 5 to 60 wt% (**Fig. 10a**). The PXRD patterns of the powders granulated with POS40 were identical to that of form II for ethanol charges of up to 30 wt% (**Fig. 10b**). However, trace amounts of the specific diffraction peaks belonging to form 0 were detected when 60 wt% ethanol was added to the granulation process. As for PEG400, specific diffraction peaks belonging to

form 0 were detected at very low intensities following the addition of 30 and 60 wt% ethanol. Interestingly, none of the diffraction peaks belonging to form 0 were observed when the granulation was conducted with 15 wt% ethanol in the presence of PEG400. It is noteworthy that the degree of crystal transition from form II to another crystal form in these powders was lower than that observed for the powders kneaded with SDS, LCT or SFE (**Fig. 10c**). Taken together, these result indicated that the kneading of form II crystals with 30 wt% ethanol in the presence of PS80 or POS40 were the optimal kneading conditions in terms of suppressing the conversion of the form II crystals to another crystalline form. Furthermore, the addition of PS80 allowed for the addition of a larger amount of ethanol when the kneading condition reached the slurry state, with the CAM crystals remaining unchanged as form II crystals. These results therefore suggest that the addition of PS80 provides a robust granulation process capable of stabilizing the form II crystals.

The influence of the additives used in the wet granulation process of form I with ethanol was also investigated in terms of its impact on the crystal transition of form I (**Fig. 11**). When PEG400, SFE, LCT or SDS were used, these additives did not affect the general crystal transition that form I transited to form 0. On the other hand, when PS80 or POS40 was used, form I completely transited to form II even though ethanol was used as the granulation solvent. Since ethanol induced the transition of CAM from

form I to form 0 as mentioned above, this crystal transition was quite unique manner.

The results listed above revealed that the addition of PS80, POS40 or PEG400 accelerated the crystal transition from form I to form II when the wet granulation of form I was conducted with water, and that the same additives also inhibited the crystal transition from form II to form 0 and subsequent form I, or promote the immediate conversion of the once transited forms 0 and subsequent form I to form II when the wet granulation of form II crystals was conducted with ethanol. Since the additional of PS80 and POS40 accelerated the crystal transition from forms 0 and subsequent form I to form II when the wet granulation of form I crystals was conducted with ethanol, PS80 and POS40 were found not to inhibit the crystal transition from form II to form I, but accelerated the crystal transition from once transited forms 0 and subsequent form I to form II. From a structural perspective, as mentioned above, these results suggested that the crystal transition of CAM was related to the interaction of the polyoxyethylene chain of the additives and the CAM molecule. Further studies using Fourier-transform infrared spectroscopy and nuclear magnetic resonance analysis would therefore shed some light on the interaction between these three additives and CAM.

Evaluation of quality of CAM tablets obtained from the composition including PS80

It was found the crystal transition of CAM could be controlled by adding PS80 to

398 the wet granulation process. Next, tablets were made from these granules using a
399 compression process with forms I and II of CAM, which were generated using a wet
400 granulation process with ethanol or water in the presence of PS80. In the absent of PS80,
401 forms I and II were confirmed not to transit to another crystal form by just mixing with
402 composites such as corn starch, L-HPC, light anhydrous silicic acid and magnesium
403 stearate (**Fig. 12**). The PXRD patterns of the tables were then investigated to confirm
404 the influence of compression process on the crystal state of the CAM (**Fig. 13**). The
405 PXRD pattern of F1, which contained form II granules that had been kneaded with
406 water containing PS80, was identical to that of form II. Tablets F2, F3 and F4 were
407 made from formulations containing form I. F2 was produced by the wet granulation of
408 form I with water in the absence of PS80. PXRD analysis of this material revealed that
409 the specific diffraction peaks belonging to form I were still present, although the
410 intensities of the specific diffraction peaks belonging to form II had increased, which
411 demonstrated that the complete transition to form II crystals had not been induced under
412 these conditions. However, the addition of PS80 led to the complete transition to form II
413 crystals, regardless of the particle size of the form I crystals, because the PXRD patterns
414 of F3 and F4 were identical to that of form II (**Fig. 13**; F3 and F4).

415 F5 and F6 were derived from a formulation involving the wet granulation of form
416 II crystals with ethanol. Specific diffraction peaks belonging to forms 0 and I were

417 observed in F5, which was prepared in the absence of PS80. In contrast, the PXRD
418 pattern of F6, which was formulated in the presence PS80, was identical to that of form
419 II. Taken together, these results demonstrate that the formulation of CAM tablets using a
420 wet granulation process with water and form I or ethanol with form II in the presence of
421 at least 5 wt% PS80 to CAM gave CAM tablets in their most stable form (i.e., form II)
422 with none of the other forms being detected, even after the compression process.

423 **Table 3** shows the pharmaceutical properties of each tablet. For the F3, F4 and F6
424 tablets, the hardness and disintegration time were significantly higher and shorter,
425 respectively, than those of F1 ($p<0.01$). As mentioned above, the crystal form of CAM
426 in all four of these formulations including F1 was form II, so the significant differences
427 in the properties of these tablets can therefore be explained in terms of the differences in
428 the localization of PS80 either on or inside the wet granules. When PS80 is localized on
429 the surfaces of the granules, the plasticity of the granulated particles and the wicking
430 time of the tablets constructed from these granules would decrease. The uniform
431 localization of PS80 inside the granules would lead to improvements in the plasticity
432 and the wicking time of the tablets. The hardness and disintegration time properties of
433 the tablets would therefore be dependent on the uniformity of PS80 distribution in each
434 formulation.

435 Finally, the influence of the PS80 on the dissolution behavior of the CAM tablets

436 was investigated because of the differences in the localization of PS80 on/inside the wet
437 granules. Various tablets were subjected to the dissolution test in different media (pH
438 values of 1.2 and 6.8) (**Fig. 14**). The dissolution behavior of the CAM tablets dissolved
439 at pH 1.2 was consistent with a zero-order release pattern that was independent of the
440 crystal form of CAM in final tablet and the addition of PS80 (**Fig. 14a**). It has been
441 reported that CAM tablets form a gel-like structure on their surface under low pH
442 conditions, and that this gel structure can prevent gastric fluid from penetrating the
443 tablet (Fujiki et al, 2011). This process could be involved in the zero-order release
444 pattern observed during the *in vitro* dissolution test at pH 1.2. In contrast, as for the
445 dissolution behavior of the F1, F3, F4 and F6 tablets, which were prepared as form II, at
446 pH 6.8, F6 showed the fastest dissolution rate, whereas F1 had the slowest initial
447 dissolution rate. These results correlated well with the particle size of CAM and the
448 disintegration time of each tablet, which suggested that there were differences in the
449 localization tendency of the PS80 on/inside the granules for the F1, F3, F4 and F6
450 tablets. Furthermore, the rate of dissolution of CAM from the F4 tablets was higher than
451 that of the F3 tablets. Because the F4 tablets were manufactured by the grinding of form
452 I CAM particles with a smaller particle size than the form I particles used in F3, this
453 result demonstrates that the rate of dissolution of CAM can be controlled based on the
454 particle size of the form I crystals. The dissolution rates of the F2 and F5 tablets were

455 slower than those of the other tablets. The extremely slow dissolution rate of F5 could
456 be attributed to the delayed disintegration of the tablet, because the F5 tablet only
457 started to disintegrate after ~30 min. This delayed disintegration could have been caused
458 by the high form I content of the F5 tablet, as shown in **Fig. 13**, because fine
459 needle-shaped crystals were reported to be formed on the surface of tablets containing
460 form I during disintegration test, which may have led to a delay in the disintegration
461 time by inhibiting the penetration of the solution into the tablet (Fujiki et al, 2015).
462 Although the disintegration time of the F2 tablets was short, the dissolution rate was
463 slow. This result suggested that the solubility of another crystal form transformed from
464 form I was lower than that of form II (**Fig. 14b**).

465 Based on the results described above, it is clear that the dissolution behavior of
466 CAM tablets manufactured with PS80 showed a zero-order release pattern at pH 1.2,
467 which was attributed to the formation of a gel on the surface of these tablets. The
468 dissolution of CAM occurred much more rapidly at pH 6.8. These dissolution behaviors
469 would therefore be ideal for the adsorption of CAM in the intestine *in vivo*.

470

471 **CONCLUSIONS**

472 In this study, we have shown that form I crystals of CAM can be completely
473 converted to the corresponding form II crystals using a wet granulation process with
474 water in the presence of PS80, POS40 or PEG400, which all possess a polyoxyethylene

chains as part of their molecular structure. Furthermore, the crystal transition of form II to any other form of CAM could not be induced by the wet granulation of form II crystals with ethanol in the presence of these additives. An evaluation of the crystal transition and physicochemical properties of CAM tablets following the addition of PS80 to the formulation process revealed that the CAM tablets contained form II crystals regardless of the crystal form of CAM or the type of solvent used for the granulation. These tablets could be used to control the dissolution behavior of CAM at pH 6.8, whilst maintaining a zero-order release pattern at pH 1.2.

This methodology is simpler and lower in cost than conventional techniques which could induce the conversion of form II CAM crystals to form I crystals. This methodology could also make it possible to develop products containing only form II CAM crystals, even if special functional polymers for improved pharmaceutical properties were used with ethanol. It is envisaged that this technology will expand the scope of formulation development.

Acknowledgments

The authors would like to thank Mr. Y. Tokunaga and Mr. T. Yanagi of Sawai pharmaceutical Co., LTD., for their helpful advices.

REFERENCES

Avrutov I, Lifshitz I, Borochovitz R, Masarwa B, Schwartz E, inventor; Teva Pharmaceutical Industries Ltd., assignee. Processes for preparing clarithromycin polymorphs and novel polymorph IV. United State patent 6599884. 2003 Jul 29.

Fujiki S, Iwao Y, Kobayashi M, Miyagishima A, Itai S., 2011. Stabilization mechanism of clarithromycin tablets under gastric pH conditions. Chem. Pharm. Bull. 59, 553–558.

Fujiki S, Watanabe N, Iwao Y, Noguchi S, Mizuguchi M, Iwamura T, Itai S. Effect of the crystalline transformation of clarithromycin on the sustained release from a tablet containing metastable polymorph form I. J. Pharm. Sci. in press.

Gruss M, inventor; Gruenenthal GmbH., assignee. Polymorph of Clarithromycin (Form V). United State patent 20080249035. 2008 Oct 9.

Jacco van de streek., 2012. Reinterpretation of the monohydrate of clarithromycin from X-raypowder diffraction data as a trihydrate. Acta. Crystllogr. C68, 0369-0372.

Iwasaki H, Sugawara Y, Adachi T, Morimoto S, Watanabe Y., 1993. Structure of 6-O-methylerythromycin A (clarithromycin). Acta Crystallogr. C 49, 1227–1230.

Liu J-H, Henry RF, Spanton SG, Riley DA, inventor; Abbott Laboratories., assignee. 6-O-methylerythromycin A crystal form III. United State patent 6627743. 2003 Sep 30.

Liu J-H, Riley DA, inventor; Abbott Laboratories., assignee. Preparation of crystal form II of clarithromycin. United State patent 5844105. 1998 Dec 1.

Liu J-H, Riley DA, Spanton SG, inventor; Abbott Laboratories., assignee. Crystal form I of clarithromycin. United State patent 5858986. 1999 Jan 12.

519 Morimoto S, Misawa Y, Asaka T, Kondoh H, Watanabe Y., 1990. Chemical modification
520 of erythromycins. VI. Structure and antibacterial activity of acid degradation
521 products of 6-O-methylerythromycin A. J Antibiot. 43, 570–573.
522 Nakagawa Y, Itai S, Yoshida T, Nagai T., 1992. Physicochemical properties and stability
523 in the acidic solution of a new macrolide antibiotic, clarithromycin, in
524 comparison with erythromycin. Chem. Pharm. Bull. 40, 725–728.
525 Noguchi S, Miura K, Fujiki S, Iwao Y, Itai S., 2012. Clarithromycin form I determined
526 by synchrotron X-ray powder diffraction. Acta. Crystallogr. C68, 041-044.
527 Noguchi S, Takiyama K, Fujiki S, Iwao Y, Miura K, Itai S., 2014. Polymorphic
528 transformation of antibiotic clarithromycin under acidic condition. J. Pharm.
529 Sci. 103, 580–586.
530 Parvez M, Arayne M.S, Sabri R, Sultana N., 2000. Clarithromycin hydrochloride
531 3.5-hydrate. Acta Crystallogr. C56, 398–399.
532 Roderiguez-Hornedo N, Murphy D., 2004. Surfactant-facilitated crystallization of
533 dehydrate carbamazepine during dissolution of anhydrous polymorph. J.
534 Pharm. Sci. 93, 449–460.
535 Sohn Y.-T, Rhee J.-K, Im W.-B., 2000. Polymorphism of Clarithromycin. Arch.
536 Pharm.Res. 23, 381–384.
537 Spanton SG, Henry RF, Riley DA, Liu J-H, inventor; Abbott Laboratories., assignee.
538 Crystal form O of clarithromycin. United State patent 5945405. 1999 Aug 31.
539 Suh K-H, Seong M-R, Kim N-D, Lee G-S, inventor; Abbott Laboratories., assignee.
540 Method of preparing form II crystals of clarithromycin. United State patent
541 6444796. 2002 Sep 3.
542 Tian J, Dalgarno S.J, Atwood J.L., 2011. A new strategy of transforming pharmaceutical
543 crystal forms. J. Am. Chem. Soc. 133, 1399–1404.
544 Tozuka Y, Ito A, Seki H, Oguchi T, Yamamoto K., 2002. Characterization and

quantitation of clarithromycin polymorphs by powder X-Ray diffractometry and solid-state NMR spectroscopy. Chem. Pharm. Bull. 50, 1128–1130.

Yajima T, Fukushima Y, Itai S, Kawashima Y., 2002. Method of evaluation of the bitterness of clarithromycin dry syrup. Chem. Pharm. Bull. 50, 147–152.

Yajima T, Umeki N, Itai S., 1999. Optimum spray congealing conditions for masking the bitter taste of clarithromycin in wax matrix. Chem. Pharm. Bull. 47, 220–225.

Table captions

Table 1. Compositions of the CAM tablets.

Table 2. Particle sizes of the untreated CAM and the hammer milled CAM samples.

Table 3. Physical properties of the CAM tablets.

559 **Table 1.**

Ingredient		Formulation					
		F1	**F2**	**F3**	**F4**	**F5**	**F6**
Granulation	Form II of CAM -intact	200.0	—	—	—	200.0	200.0
	Form I of CAM -intact	—	200.0	200.0	—	—	—
	Form I of CAM - hammer milling	—	—	—	200.0	—	—
	Corn starch	52.4	62.4	52.4	52.4	62.4	52.4
	L-HPC	40.0	40.0	40.0	40.0	40.0	40.0
	Light anhydrous silicic acid	5.0	5.0	5.0	5.0	5.0	5.0
	Polysorbate 80	10.0	—	10.0	10.0	—	10.0
	Granulation solvent	Water	Water	Water	Water	Ethanol	Ethanol
Before compression	Light anhydrous silicic acid	3.0	3.0	3.0	3.0	3.0	3.0
	Magnesium stearate	9.6	9.6	9.6	9.6	9.6	9.6
Total		320.0	320.0	320.0	320.0	320.0	320.0

560 The each value represents the amount (mg/tablet) of each additives added in CAM tablet.

561

562 **Table 2.**

Form of CAM	Particle size (μm)			
	Intact		Ground	
	D_{50}	D_{90}	D_{50}	D_{90}
II	3.1 ± 0.4	12.9 ± 0.7	—	—
I	25.1 ± 2.6	100.3 ± 8.2	16.5 ± 0.9	47.2 ± 3.2

563 Each data represents the mean value ± S.D. (n=3).

564

565

566 **Table 3.**

Formulation	Hardness (N)	Thickness (mm)	Disintegration time (min)
F1	60.0 ± 2.6	5.03 ± 0.02	9.3 ± 0.5
F2	117.7 ± 8.3*	5.25 ± 0.02	1.0 ± 0.2*
F3	93.7 ± 1.5*	5.10 ± 0.01	3.6 ± 0.2*
F4	107.0 ± 7.2*	5.14 ± 0.01	2.6 ± 0.1*
F5	132.0 ± 5.0*	5.06 ± 0.03	28.0 ± 3.0*
F6	83.3 ± 5.1*	5.07 ± 0.01	4.4 ± 0.8*

567 Each data represents the mean value ± S.D. (n=3). * p<0.01, compared with F1.

Figure legends

Fig. 1. PXRD patterns of forms I and II, and the wet granulation powders of form I prepared with 30 wt% water in the absence of the surfactants

Open and closed circles represent the diffraction peaks characteristic to forms I and II, respectively.

Fig. 2. PXRD patterns of the wet granulation powders of form I prepared with 30 wt% water in the presence of (a) SDS, (b) LCT and (c) SFE.

Open and closed circles represent the diffraction peaks characteristic to forms I and II, respectively.

Fig. 3. PXRD patterns of the wet granulation powders of form I prepared with 30 wt% water in the presence of (a) PS80, (b) POS40 and (c) PEG400.

Open and closed circles represent the diffraction peaks characteristic to forms I and II, respectively.

Fig. 4. DSC thermograms of forms Ⅰ, Ⅱ and the wet granulation powders of form I prepared with 30 wt% water in the presence of PS80, POS40 or PEG400.

Fig. 5. Effect of the amount of water added during the granulation of form I (a) in the absence of surfactants, and in the presence of (b) 5 wt% SDS, (c) 5 wt% LCT and (d) 5 wt% SFE, on the PXRD patterns of the resulting wet granulation powders.

Open and closed circles represent the diffraction peaks characterized by forms I and II, respectively.

Fig. 6. Effect of the amount of water added during the granulation of form I CAM crystals in the presence of (a) 5 wt% PS80, (b) 5 wt% POS40 and (c) 5 wt% PEG400, on the PXRD patterns of the resulting wet granulation powders.
Open and closed circles represent the diffraction peaks characterized by forms I and II, respectively.

Fig. 7. PXRD patterns of the wet granulation powders of form II prepared with 30 wt% water in the absence or presence of a surfactant or polymer.
Open circles, closed circles and open triangles represent the diffraction peaks characterized by forms I, II and 0, respectively.

Fig. 8. PXRD patterns of the wet granulation powders of form II prepared with 30 wt% ethanol in the absence or presence of a surfactant or polymer.
Open circles, closed circles and open triangles represent the diffraction peaks characterized by forms I, II and 0, respectively.

Fig. 9. Effect of the amount of ethanol added during the granulation of form II in (a) the absence of surfactants, and in the presence of (b) 5 wt% SDS, (c) 5 wt% LCT and (d) 5 wt% SFE, on the PXRD patterns of the resulting wet granulation powders.
Open circles, closed circles and open triangles represent the diffraction peaks characterized by forms I, II and 0, respectively.

Fig. 10. Effect of the amount of ethanol added during the granulation of form II in the presence of (a) 5 wt% PS80, (b) 5 wt% POS40 and (c) 5 wt% PEG400 on the PXRD patterns of the resulting wet granulation powders.

Open circles, closed circles and open triangles represent the diffraction peaks characterized by forms I, II and 0, respectively.

Fig. 11. PXRD patterns of the wet granulation powders of form I prepared with 30 wt% ethanol in the absence or presence of a surfactant or polymer.

Open circles, closed circles and open triangles represent the diffraction peaks characterized by forms I, II and 0, respectively.

Fig. 12. PXRD patterns of the physical mixture of form I or form II and excipients without any surfactant. Open circles and closed circles represent the diffraction peaks characterized by forms I and II, respectively.

Fig. 13. PXRD patterns of the various CAM tablets and a mixture of excipients.

Open circles, closed circles and open triangles represent the diffraction peaks characterized by forms I, II and 0, respectively.

Fig. 14. Dissolution behaviors of various CAM tablets at (a) pH 1.2 and (b) pH 6.8.

Each point represents the mean value ± S.D. (n=3).